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LEVEL II

UNITED STATES AIR FORCE
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Wright-Patterson Air Force Base, Ohio

LEVEL

2

A SIMULATION OF THE BASE CIVIL ENGINEERING WORK REQUEST/ WORK ORDER SYSTEM

Ernest C. St. Gelais, 1st Lt, USAF

LSSR 94-81

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In recent years the Base Civil Engineering organization has seen a reduction in real terms in the growth of its budget necessitating an emphasis toward increasing productivity within civil engineering. This research models the work request/work order system using Q-GERT, a computer simulation language, in order to increase the productivity of the system and to help improve customer satisfaction with civil engineering. To increase productivity, the model can evaluate potential changes to the system and can provide information to managers so they can make better decisions. To help improve customer satisfaction, the model can estimate the mean processing time for work orders in the system in order to give the customer an idea of when the work will start. The results of this research indicate that this model can be particularly effective as a decision-making tool for managers. To highlight the decision-making capabilities of the model, this research presents several decision aids derived from testing the model. The decision aids presented represent a small sample of the numerous aids which can be formulated from this model.

LSSR 94-81

A SIMULATION OF THE BASE CIVIL ENGINEERING WORK REQUEST/WORK ORDER SYSTEM

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

Ernest C. St. Gelais, BS
First Lieutenant, USAF

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CHAPTER I

INTRODUCTION TO THE RESEARCH

Overview

The Air Force Civil Engineering (AFCE) organization is a service organization tasked with maintaining over 727 million square feet of buildings, 150,000 family housing units, 265 million square yards of airfield pavements, and 292 million square yards of streets and parking areas at over 3100 installations worldwide. The cost to America's taxpayers to perform the AFCE mission amounts to about $3 billion annually (6:80). In recent years, however, the Base Civil Engineer (BCE)[1] has seen a cutback in real terms in the growth of his budget. Now, more than ever before, the BCE is faced with increasing the productivity of his work force in order to continue to adequately fulfill his support mission. As Major General Gilbert, the Air Force Director of Engineering and Services, notes,

> Increased competition for limited funding will necessitate that we do more with less. The Air Force must take the initiative in employing current state-of-the-art productivity techniques to ensure the best facility maintenance within available resources [6:80].

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[1]BCE is an abbreviation commonly used for both the Base Civil Engineer and Base Civil Engineering. Its meaning should be clear from the context.

Two techniques presently being used by AFCE to increase productivity are: (1) changing current procedures within civil engineering (CE) in order to make them more efficient, and (2) providing better information to managers so they can make more informed decisions.

One way in which AFCE changes current procedures is through the use of Civil Engineering and Services Management Evaluation Teams (CESMET) organized at the Air Staff and major air command levels "to disseminate the many innovative ideas employed at various locations that could affect productivity at other Air Force bases [6:81]." Test and evaluation is another method used by AFCE to change current procedures. In this method, several bases are employed as test bases for a potential procedural change and the change is evaluated prior to a decision being made on implementation. Although the two methods just discussed seem to be working well enough, their high costs make it difficult to justify the increased productivity they provide.

AFCE is presently dealing with the problem of providing better information to managers through an ongoing information requirements study begun in March 1980. This study calls for first identifying the information requirements of managers within civil engineering and then designing and implementing new systems within civil engineering to provide that information. Unfortunately, the

management information system envisioned by this study is not scheduled to be fully operational before 1985 at the earliest (4).

In addition to the productivity problem, CE has long faced a problem with its image. Again Major General Gilbert writes, "Image is based upon the perceptions of the people we serve, work with, and work for. It is also based upon the results we achieve [7:3]." The importance of image was further highlighted in a report written in 1978 by Lieutenant Colonel Burgess (3). Lieutenant Colonel Burgess determined that the two most important performance indicators for a BCE organization are credibility to meet commitments and satisfaction of base personnel with civil engineering. For the sake of simplicity this research will use customer satisfaction to encompass General Gilbert's term, image, and the two performance indicators from Colonel Burgess' study.

Within civil engineering, the branch which utilizes the most manpower (by far), spends the most money, and interacts most with customers is the Operations branch. Therefore, Operations is the area in CE with the greatest potential for increasing productivity and customer satisfaction.

Background

The Operations branch is only one of several branches within the BCE organization. As shown in Figure 1, BCE is normally composed of six branches: the Squadron Section and Administration; Family Housing; Industrial Engineering; Operations; Fire Protection; and Engineering and Environmental Planning. Financial Management is normally not considered a branch though its function is distinct and vital to the BCE organization.

The Operations branch performs all the in-house work[2] for civil engineering. In-house work can be divided into job orders and work orders. Work orders generally require higher approval levels, more funds, longer material lead times, and more planning than do job orders. So it appears that greater gains can be made in increasing productivity and customer satisfaction by considering in-house work orders as opposed to job orders. For this reason and the availability of data which will be discussed later, this research concerns itself only with the work request/work order system within civil engineering.

Within the Operations branch, the Resources and Requirements (R&R) section is chiefly responsible for the work request/work order system. In particular, this section

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[2]Work accomplished by civil engineering can be classified into two broad categories: (1) in-house work which is performed by CE personnel, and (2) contract work performed by non-government personnel.

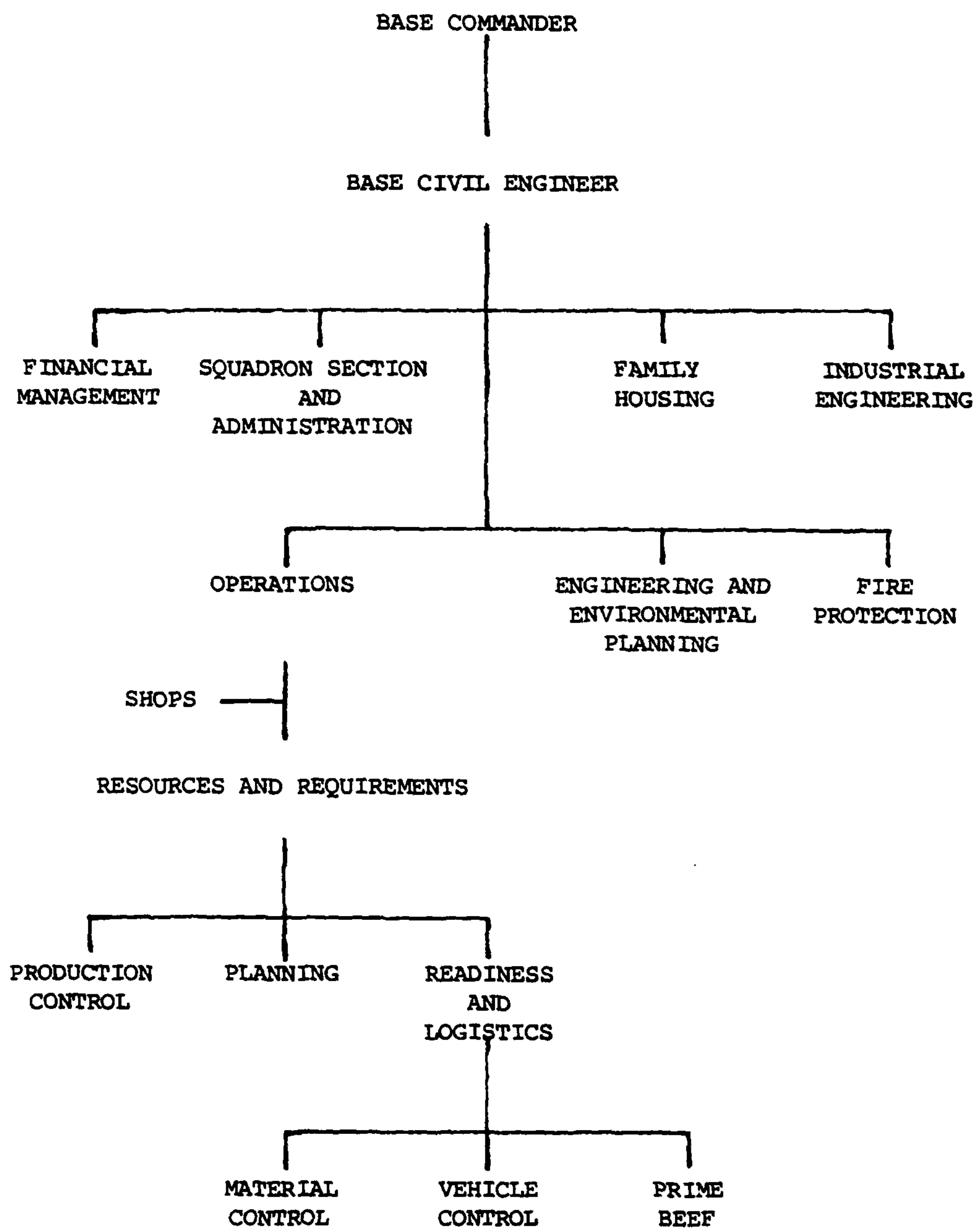

Fig. 1. Base Civil Engineering Organization

is responsible for identifying work; processing work requests and work orders; ordering, acquiring, and stocking materials; and planning and scheduling work for shop personnel in the Operations branch. The R&R section (see Figure 1) is broken into three subsections: Production Control, Planning, and Readiness and Logistics (R&L). R&L is further divided into Material Control, Vehicle Control, and Prime BEEF. The three subsections which perform functions relative to the work request/work order system are: Production Control, Planning, and Material Control. The procedures for processing work requests and work orders are outlined in AFR 85-1, Chapters 4 and 8. Figure 2 provides a visual representation of the flow of work orders through the system while the paragraphs which follow provide short descriptions of the functions performed by Production Control, Planning, and Material Control.

Production Control

This subsection is responsible for processing work requested by customers, channeling the work requests/work orders through the system, and monitoring their progress. If a work request is cancelled or disapproved, the Production Control Center (PCC) through its Customer Service Unit (CSU) is responsible for notifying the customer. In addition, it is the CSU which first receives the work request

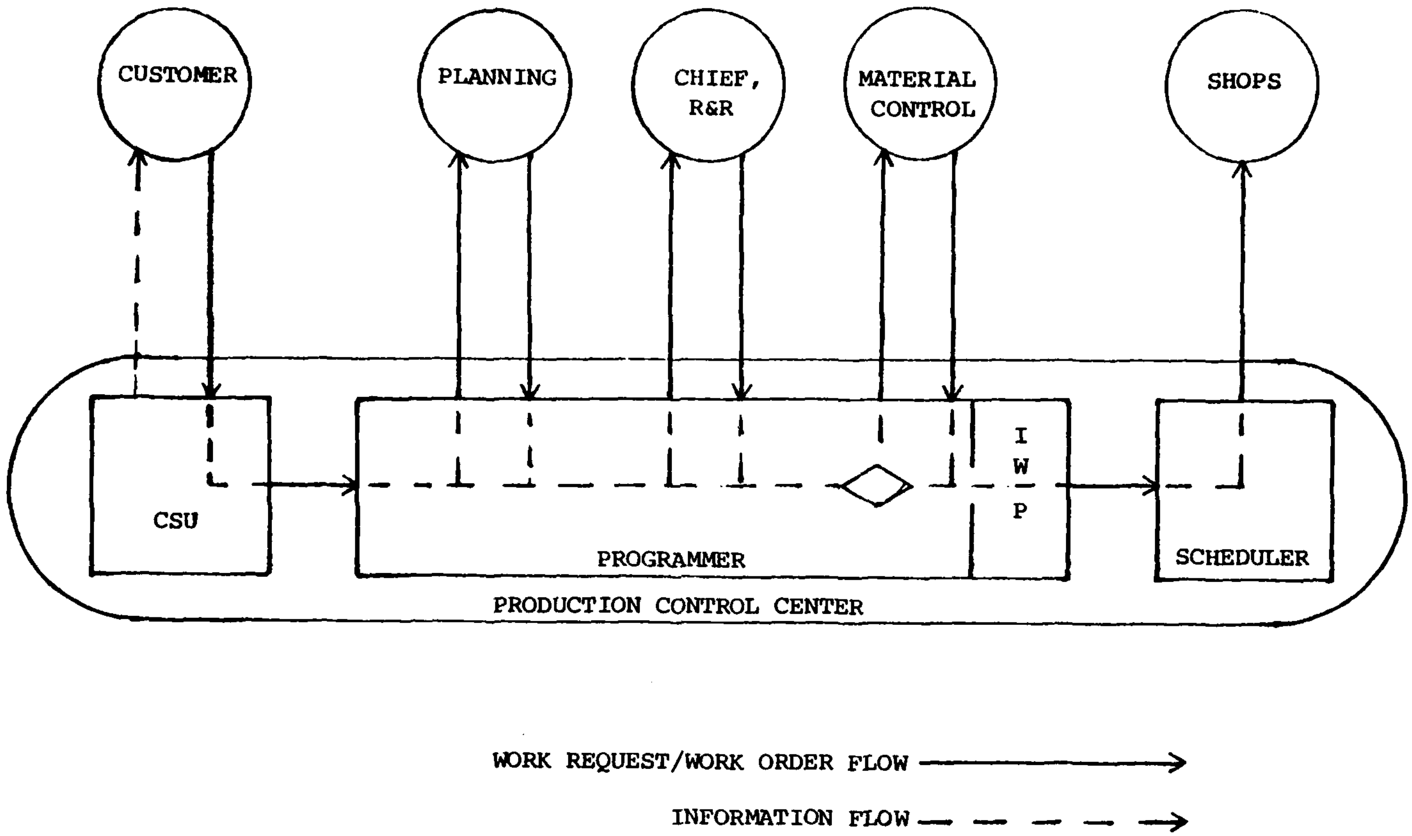

Fig. 2. Work Request/Work Order System

and which interfaces with the customer throughout the process. Other personnel in the PCC perform functions in the process as well. For instance, the programmer is responsible for updating work order data in the Base Engineer Automated Management System (BEAMS), monitoring the flow of work orders, obtaining final authorization from the Chief of R&R, and programming material complete work orders into the Inservice Work Plan (IWP) (14:Chapter 13). The scheduler takes work orders from the Current Month IWP furnished by the programmer in order to schedule work for the shops.

Planning

As regards the work request/work order system, the job of the Planning subsection is fairly straightforward. The planners determine the necessary skills, materials, and approximate manhours required to accomplish a work request/work order. The planners use Engineered Performance Standards and personal experience to determine the skills and manhours required for a job. The materials required for a work order, and whether they are on hand or must be ordered, are annotated on an Air Force Form 1445. Once these steps are completed the work order is sent back to the PCC for further processing.

Material Control

Material Control is responsible for providing material support for all of civil engineering. For the

work request/work order system this subsection orders, acquires, and stocks materials for work orders. Once all the material for a work order is obtained, the work order is sent to the PCC where it is programmed into the IWP. If a work order does not require that materials be ordered, that work order bypasses Material Control and is programmed directly into the IWP.

Simulation of the System

Having just completed a short description of the processes involved in the work request/work order system the question arises as to how to best increase productivity and customer satisfaction with the system. The management technique chosen for this research is simulation. Simulation is generally cheaper than actual (physical) experimentation and also "allows time compression, whereby a simulation accomplishes in minutes what might require years of actual experimentation [2:477]." To use simulation a system is first modeled mathematically and then tested using computer resources. A mathematical model of the work request/work order system could provide evaluative, informative, and estimative capabilities that might increase productivity and customer satisfaction.

As an evaluation tool, the model could be used at the base, major air command, or Air Staff levels to determine the effect of implementing changes to processes within

the system. For instance, it could be used to determine what could happen to the mean processing time of work orders if the IWP is automated as is currently being considered (9). The model could eventually eliminate the need for the costly test base approach used today for testing proposed changes to the system prior to implementation.

As a decision-making tool, the model could provide the Chief of R&R with better information with which to make a decision. For example, if the Chief of R&R wanted to know the effect on work order processing time of having more than two planners on leave at one time, the model could provide that to him. (Matrices and decision aids developed from the model will be presented in more detail later.) The evaluative and informative capabilities of a model of the work request/work order system should help to increase productivity by increasing the efficiency and effectiveness of the system.

As an estimation tool, the model could provide the customer with an estimate of when the work should start so that the customer can plan related activities around the CE work. Currently the CSU has no means for providing the customer with an estimate of when work will start. It seems fairly certain that the estimating capability of the model will increase customer satisfaction with civil engineering.

Statement of the Problem

There exists a real need within Air Force Civil Engineering for a mathematical model of the work request/work order system which: (1) can be used to evaluate changes to the system, (2) can provide information to managers with which to make better decisions, and (3) can provide realistic time estimates of the mean processing time for work orders from receipt through to work start.

Recent Relevant Research

Although insuring the proper functioning of the work request/work order system is one way to increase productivity and customer satisfaction, only a handful of previous studies have dealt specifically with this problem.

The first study, conducted by the Air Force Data Systems Design Center (AFDSDC) in 1973 (5), considered the feasibility of automating the now manual Inservice Work Plan. As indicated previously, material complete work orders are programmed into the IWP prior to being sent to the shops to start work. The AFDSDC study recommended the use of Cathode Ray Tube (CRT) technology as a source of data input and retrieval of information concerning programmed work orders. The principal purpose of the CRT was "to prevent the IWP from becoming out of date soon after it is produced [5:4]." As mentioned earlier, a scaled-down version of the alternative recommended in the AFDSDC

study is currently undergoing testing at eight Air Force bases in the U.S. If the model proposed by this research is fully implemented the parameters used to quantify the model might need to be modified.

Another study was conducted by Lieutenant Nicholas Salerno at Auburn University in 1977 (12). Lt. Salerno proposed an automated work request tracking system which would use a CRT to, among other things, eliminate redundant paperwork, provide easy access to work request status, and provide for easy transference of work request data among various subsections. Lt. Salerno recommended a phased implementation of his automated tracking system. Like the AFDSDC study, Lt. Salerno's recommendation, if implemented, could alter the basic flow of the work request/work order system and, therefore, require structural changes within the model proposed by this research.

The third, and final, study discussed in this section was conducted in 1979 by Captains Arnold and Fogleman (1). In their thesis, Arnold and Fogleman attempted to model the work request/work order system using Q-GERT, a computer simulation language. Unfortunately, computer and time constraints left them unable to operationalize or test their model. They did, however, succeed in modeling the system using Q-GERT and their feeling was that simulation of the work request/work order system was possible. This research carries forward the basic work accomplished

by Arnold and Fogleman. In particular, this research uses Arnold and Fogleman's data and model to develop a modified model of the work request/work order system for subsequent operationalization, validation, and testing. Specific uses of the data and model from Arnold and Fogleman's thesis are discussed in more detail in the next chapter.

CHAPTER II

DATA ACQUISITION AND MODEL DEVELOPMENT

Overview

This chapter discusses the data employed to develop the model of the work request/work order system. A general description of the model is presented to help the reader understand how the model works. Following this description of the model an example is given which demonstrates how the system was modeled using Q-GERT. After the example, the process of checking for errors in the data and model presented by Arnold and Fogleman is discussed. Next, the types of output acquired from the simulation of the work request/work order system are addressed. The chapter ends with a presentation of four research objectives.

Data Used in Model Development

As mentioned previously, the model used in this research is a modified version of a simulation developed by Arnold and Fogleman. To develop their model Arnold and Fogleman acquired work request/work order data from Barksdale AFB for a two-year period beginning 1 March 1977 and ending 28 February 1979. Arnold and Fogleman obtained key dates and attributes for each work request and work order from work order folders of completed work, from the

Work Order History Tape,[1] and from various logs kept by subsections within civil engineering including: Planning, Material Control, the Customer Service Unit, and Scheduling. Figure 3 lists the items collected for each work request or work order. In all, Arnold and Fogleman collected data on 1222 work requests and 259 work orders for use in designing their model of the work request/work order system.

General Description of the Model

This research uses Q-GERT, "a network modeling vehicle and a computer analysis tool [11:vii]," to model the work request/work order system in order to obtain mean work order processing times for the system. The Q-GERT Analysis Program developed by Pritsker (11) was used to simulate the generation of work requests, the processing of work orders through various subsections within the Operations branch, the queueing of work orders within subsections and within the IWP, and the scheduling of work orders to the shops. In the following section a macro view of the functions of the two major subsystems of the model is presented, followed by a short example illustrating the development of the model using Q-GERT.

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[1]Work Order History Tape is a master file which contains several items of information regarding completed work orders. This file is a computer record maintained for a moving twelve-month period.

WORK REQUEST DATA

Work request number
Date received
Date to and from planning
Date to and from engineering
Date to and from the PCC
Date to and from the Chief, R&R
Date to the CSU
Date to scheduling
Initial number of planning hours

WORK ORDER DATA

Work order number
Date received
Estimated manhours
Actual manhours
Work class
Number of shops
Special interest code
Priority
Estimated materials
Actual materials
Date to and from planning
Date to and from engineering
Date approved
Date to scheduling
Date in and out of material control
Planning manhours required
Date authorized
Work start date
Work completion date

Fig. 3. Data Items Collected from Barksdale AFB

The Model: A Macro View

As shown in Figure 4, the simulation model of the work request/work order system is divided into two major subsystems labeled: the work request subsystem and the work order subsystem.

Work Request Subsystem. This subsystem simulates the functions performed from the time the customer requests the work until the work order is sent to Planning. Within this subsystem some of the work requests are disapproved or cancelled and the work orders are ejected from the system. This process simulates the real life situation of the CSU notifying the customer that a work request is rejected. The other work requests processed by this subsystem become either contract work, job orders, or work orders. Again, the system ejects contract work and job orders, allowing only work orders to continue through the system. These work orders, which amount to approximately 30 percent of the work requests originally generated, become inputs for the other subsystem in the model--the work order subsystem.

Work Order Subsystem. This subsystem simulates the functions performed from the time the work order is sent to Planning until the work order is scheduled for work start. Therefore, the functions performed within this subsystem include: planning the work, authorizing funds for

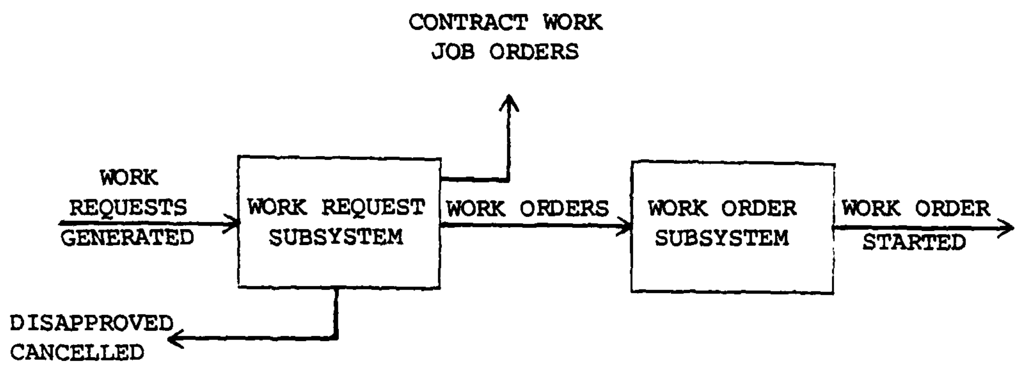

Fig. 4. Macro View of the Model

the work, ordering and acquiring materials, programming the work order into the IWP, and scheduling the work to the shops. The output from this subsystem is a work order which has run through the model and is sent to the shops for work start.

An Example of Q-GERT Modeling

This section presents an example of how nodes and branches are used in the model and how processing times are simulated. The specific process which will be presented is the ordering and acquiring of materials by the Material Control subsection. This process is part of the work order subsystem. In the real world process, work orders are sent from the PCC to Material Control if materials need to be ordered. When the work order arrives at Material Control, materials are ordered if an individual is available to fill out the necessary paperwork. If not, the work order is set aside until someone becomes available. Once the material is ordered, no further action is taken on the work order until all the materials for that work order are acquired by Material Control. This material acquisition period is usually referred to as the material lead time. Its length varies depending upon several factors such as size of the job, number of shops involved, priority of the work, etc. Once all the materials are

acquired the work order is annotated and sent back to the PCC for further processing.

Use of Nodes and Branches. In general, in Q-GERT, nodes represent milestones, queues, or decision processes while branches represent activities or servers (11:4). The nodes and branches shown in Figure 5 is a Q-GERT representation of the process performed by the Material Control subsection for ordering and acquiring materials for work orders. Node 32 represents the arrival and queueing of work orders in Material Control. Branch 44 simulates the ordering of materials for a work order by an individual in Material Control, though up to three may be ordering at any one time. Node 40 represents the completion of the ordering activity and the start of the acquiring activity. Branch 45 simulates the material lead time required to obtain the materials for a work order. Node 41 represents the completion of the acquiring process and the annotation of the work order prior to sending it to the PCC for further processing.

Simulating the real world process by using nodes and branches represents only the structural part of Q-GERT modeling. In addition to this network structure, certain parameters must be simulated in order to fully model the system. The following section presents an example of how parameters are simulated.

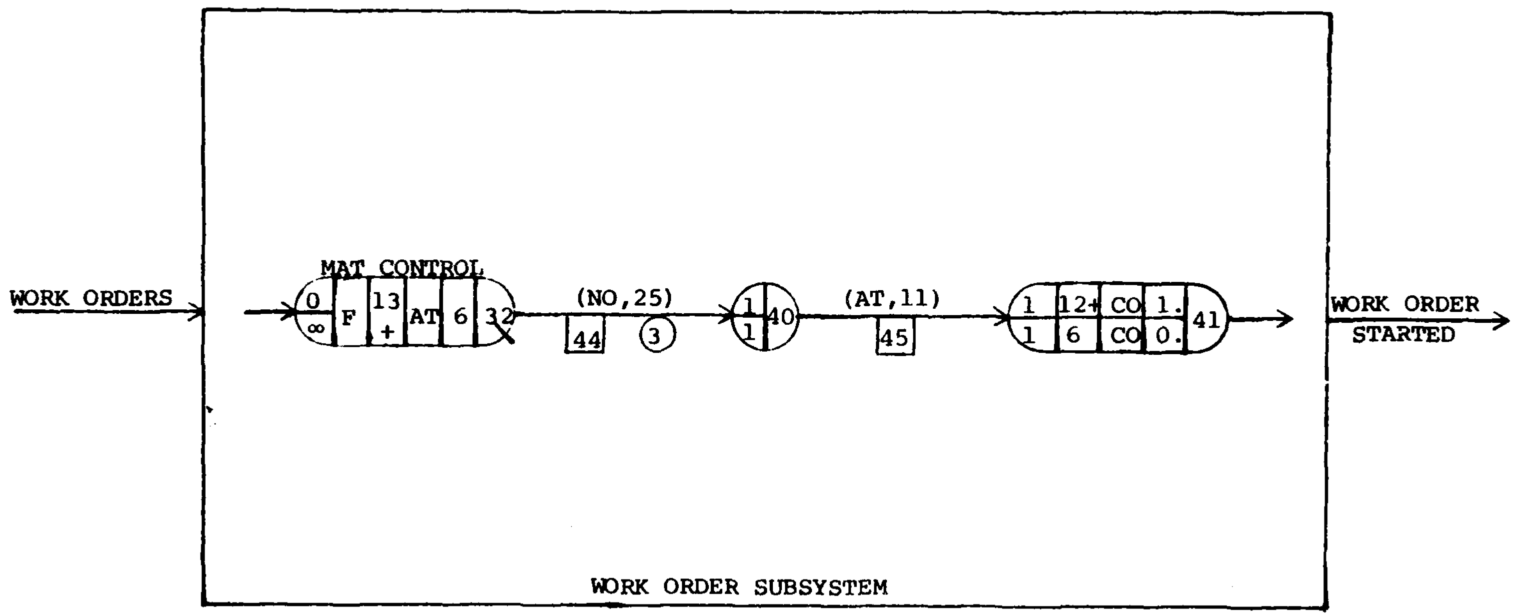

Fig. 5. Material Control Network

Use of Barksdale Data to Simulate Activity Times. In their thesis, Arnold and Fogleman performed regression analysis on the Barksdale data to obtain estimates for key variables such as estimated manhours, planning time, material control time (material lead time), etc. For example, Arnold and Fogleman regressed material lead time with number of shops, estimated materials, and each work class, special interest code, and priority to obtain the equation for material lead time shown in Figure 6. This equation was incorporated into the model, symbolized in Figure 5 by (AT,11), to provide an estimate of the activity time for branch 45.

MATERIAL LEAD TIME = 2.8997(NUMBER OF SHOPS) + 0.0041 (ESTIMATED MATERIALS) + WORK CLASS + SPECIAL INTEREST CODE + PRIORITY + 87.1651

Fig. 6. Regression Equation for Material Lead Time

They also used the Barksdale data to determine average activity times for time between arrivals of work requests, CSU processing time, time from authorization to Material Control, material ordering time, etc. By analyzing the data and obtaining means and variances, Arnold and Fogleman were able to determine the distributions for these activity times. For example, they determined that the material ordering times followed a normal distribution with a mean of 0.02 days and a variance of 0.003. They

used this information to simulate the activity time (see Appendix B), symbolized in Figure 5 by (NO ,25), for branch 44.

Checking Arnold and Fogleman's Data and Model

Since the model and much of the data used in this research were acquired from a previous research effort, its accuracy is subject to numerous possible errors such as transcription errors, typographical errors, errors of omission, etc. Therefore, the data and model had to be checked prior to using it for this research. The data and model were checked by using some of the same analyses performed by Arnold and Fogleman to develop their model. For example, one check involved using the SPSS[2] subprogram FREQUENCIES with its option 8 which prints a histogram of absolute frequencies in a cell to check the FREQUENCIES output for the work order data for date received and work completion date with Figure 19 in the Arnold and Fogleman thesis which provides the output from their analysis using FREQUENCIES. This check and every other check of the Arnold and Fogleman data confirmed that the data was transcribed accurately.

The Q-GERT model was checked through several hours of manual checks and numerous computer runs. As an example,

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[2]SPSS is an abbreviation for Statistical Package for the Social Sciences. It is a collection of statistical computer programs which enables users to perform a variety of statistical tests.

the estimated cost statements employed in the model were checked against the levels of approval authority for Barksdale AFB found in Table 1 (1:35). Also, the regression equations used in the model to set values for estimated manhours, planning man-days, planning time, material control time, time to start, and in progress time were checked with Tables 6 through 12 (1:57-63). All of the manual checks confirmed that the model was transcribed accurately. However, during the numerous computer runs of the model, several FORTRAN[3] statements were missing which would make operationalization of the model impossible. An example of one such statement is REAL NO which was missing from the specification statements in the program. Without this statement the model could not possibly run as designed. All missing statements were added and became part of the modified model used in this research. The next section discusses the types of outputs acquired from a computer simulation of this modified model.

Data Acquired from the Model

The Q-GERT Analysis Program provides several types of output from simulation runs of a model such as node statistics, histograms, server utilization, etc. However, the only output types important to this research are the

---

[3]FORTRAN is the computer programming language used to program the Q-GERT simulation package.

node statistics which provide the number of observations or work orders arriving at a node and their average arrival time (see Table 1) and the frequency distribution of processing times for work orders arriving at work start. These output types are important because they provide the data necessary to satisfy the research objectives presented in the next section. For example, the mean work order processing time acquired from node 50 serves as the performance indicator or response variable (see Shannon (13:14)) for the model. The uses of the data acquired from the model are discussed more fully in Chapter III.

TABLE 1

SAMPLE OUTPUT FROM Q-GERT MODEL

		NODE STATISTICS			
NODE	LABEL	AVE.	STD. DEV.	NO OF OBS.	STAT TYPE
50	WK STRT	132.1016	75.2764	264.	I
27	WO INTER	1.2934	1.3713	389.	B
26	WORK ORD	4.8837	14.7825	390.	I
25	CONTRACT	4.5767	8.7424	91.	I
24	JOB ORDR	4.8824	10.8215	322.	I
21	DISAPPR	4.7343	11.8882	96.	I
8	CANCELED	5.9441	21.6419	87.	I
4	UNACCEPT	.0551	.0185	227.	I

Research Objectives

The following are the objectives of this research:

1. To verify that the model presented by Arnold and Fogleman, and modified in this research, is still valid according to the procedures used in civil engineering today.

2. To operationalize the model through the use of computer simulation.

3. To internally validate the model.

4. To test the model's sensitivity to changes in several factors affecting the mean work order processing time.

CHAPTER III

RESEARCH METHODOLOGY

Overview

This chapter presents the methodology this research employed to satisfy the research objectives stated in the last section. Each objective is addressed separately since they are distinctly different from one another. Also discussed are the assumptions made in order to carry out the research and the limitations imposed on the research.

Research Objective Number 1

To verify that the Q-GERT model presented by Arnold and Fogleman, and modified in this research, is still valid according to the procedures used in civil engineering today.

Satisfaction of this objective was required in order to confirm the applicability of using such a model as an evaluation tool, decision-making tool, and estimation tool in the BCE organization today. To satisfy this objective, the Q-GERT model and accompanying network presented by Arnold and Fogleman (1:Appendices E and F) were checked for agreement with AFRs 85-1, 85-10, and 86-1 and recent changes to these regulations. In addition, the researcher used his personal CE experience and the CE experience of several other CE officers to verify the model.

Research Objective Number 2

To operationalize the model through the use of computer simulation.

As indicated previously, the Q-GERT Analysis Program was used to run the model to make it operational. Since this is the point which blocked Arnold and Fogleman from completing their original objectives, it was anticipated that several difficulties would arise during this segment of the research. In particular, Q-GERT error type 14, "Insufficient space available to store attributes of transactions [11:438]," stopped Arnold and Fogleman in their thesis. It was anticipated that by running the model with the larger version of Q-GERT now available on the CDC computer this obstacle could be overcome. Failing that, the number of attributes for each transaction would be reduced to possibly overcome space limitations.

Research Objective Number 3

To internally validate the model.

The test chosen to satisfy this objective was the Chi-Square goodness of fit test developed by Ronald Fisher in 1924 (13:76). Data from each subsystem of the model was used to perform the validation. From the work request subsystem, work request data was compared to the work request data from Barksdale AFB shown in Table 2. The null and alternate hypotheses for this test were:

TABLE 2

BARKSDALE WORK REQUEST DATA

Cell	Absolute Frequencies	Relative Frequencies (Pct)
Work Order	367	30.03
Contract	84	6.88
Job Order	339	27.74
Disapproved	89	7.28
Cancelled	101	8.27
Unacceptable	242	19.80
TOTALS	1222	100.00

H_0: *The work request data from the model follows the same distribution as the Barksdale work request data.*

H_1: *The work request data from the model does not follow the same distribution as the Barksdale work request data.*

From the work order subsystem, work order processing time data from node 50 of the model (see Appendix A) was compared to the work order processing time data from Barksdale AFB shown in Table 3. The null and alternate hypotheses for this test are:

H_0: *The work order processing time data from the model follows the same distribution as the Barksdale work order processing time data.*

H_1: *The work order processing time data from the model does not follow the same distribution as the Barksdale work order processing time data.*

TABLE 3

BARKSDALE WORK ORDER DATA

Cell (Days)	Absolute Frequencies	Relative Frequencies (Pct)	Cumulative Frequencies (Pct)
0- 20	25	10.3	10.3
21- 40	28	11.5	21.8
41- 60	14	5.8	27.6
61- 80	18	7.4	35.0
81-100	22	9.1	44.0
101-120	23	9.5	53.5
121-140	24	9.9	63.4
141-160	16	6.6	70.0
161-180	19	7.8	77.8
181-200	11	4.5	82.3
201-220	4	1.6	84.0
221-240	5	2.1	86.0
241-260	9	3.7	89.7
261-280	8	3.3	93.0
281-300	4	1.6	94.7
301-320	0	0.0	94.7
321-340	4	1.6	96.3
341-360	1	0.4	96.7
360-380	0	0.0	96.7
380-INF	8	3.3	100.0
Totals	243	100.0	-

Each set of data was tested using the format specified in Table 4. Data from the model provided the observed frequencies while the Barksdale data provided the expected frequencies. Once the indicated arithmetic operations were performed and the χ^2_{TAB}[1] values obtained, that value was compared with $\chi^2_{(c-1)}$[2] at an α significance level of 0.05. If $\chi^2_{TAB} < \chi^2_{(c-1,\alpha)}$ then the null hypothesis could not be rejected and the distributions were considered the same. Failing to reject both null hypotheses would indicate that the model was internally valid, whereas, the rejection of either null hypothesis would mean that the model was not internally valid.

Research Objective Number 4

To test the model's sensitivity to changes in several factors affecting the mean work order processing time.

The work request/work order simulation is designed to provide the mean processing time for work orders from their receipt by the CSU to work start by the shops. Some of the factors which could affect this processing time are listed on the next page:

---

[1]The χ^2_{TAB} value was obtained by summing the last column in Table 4.

[2]$\chi^2_{(c-1,\alpha)}$ was obtained from a table of critical values for the χ^2 distribution, where c represents the number of cells and c-1 represents the degrees of freedom.

TABLE 4

FORMAT FOR CHI-SQUARE TEST

Cells	Observed Frequencies (O_i)	Expected Frequencies (E_i)	$\frac{(O_i - E_i)^2}{E_i}$
C_1	O_1	E_1	X.XX
C_2	O_2	E_2	X.XX
C_3	O_3	E_3	X.XX
.	.	.	.
.	.	.	.
.	.	.	.
	XXX	XXX	χ^2_{TAB}=XX.XX

A. Number of planners available to work on work orders

B. Material lead time

C. Chief of Resources and Requirements Availability

D. Material Control servers available to order materials

E. Work order class

F. Work order special interest code

G. Work order priority

H. Number of shops involved on a work order

From this list, factors A, B, and C were chosen to test their effects on the mean processing time. Each factor has three levels (shown on Figure 7). Their effect was

Factor	Levels of Factor
A: Number of Planners Available	i: 1. Pessimistic (4)* 2. Most Likely (5) 3. Optimistic (6)
B: Material Lead Time	j: 1. Slow (4/3 Avg)** 2. Average (Avg) 3. Fast (2/3 Avg)
C: Chief of R&R Availability	k: 1. Pessimistic (0.05)*** 2. Most Likely (0.10) 3. Optimistic (0.15)

Fig. 7. Factors and Their Levels

*The number of planners (4) available for this level.

**The length of the material lead time (4/3 avg) for this level.

***The portion of the day (0.05) that the Chief of R&R was available for processing work orders.

tested by using a three-factor analysis of variance (ANOVA) and, where appropriate, the Tukey method of multiple comparisons.

The data used to supply values for the response variable consisted of 54 mean work order processing times. In choosing the sample size, care was taken to provide at least 10 degrees of freedom for the error term as suggested by Shannon (13:164). Each of the 54 data points is a grand mean obtained by completing 30 runs of the simulation model, each run being equivalent to 504 workdays. To obtain two data points per cell as shown in Figure 8 the factor levels were altered for every two batch runs of

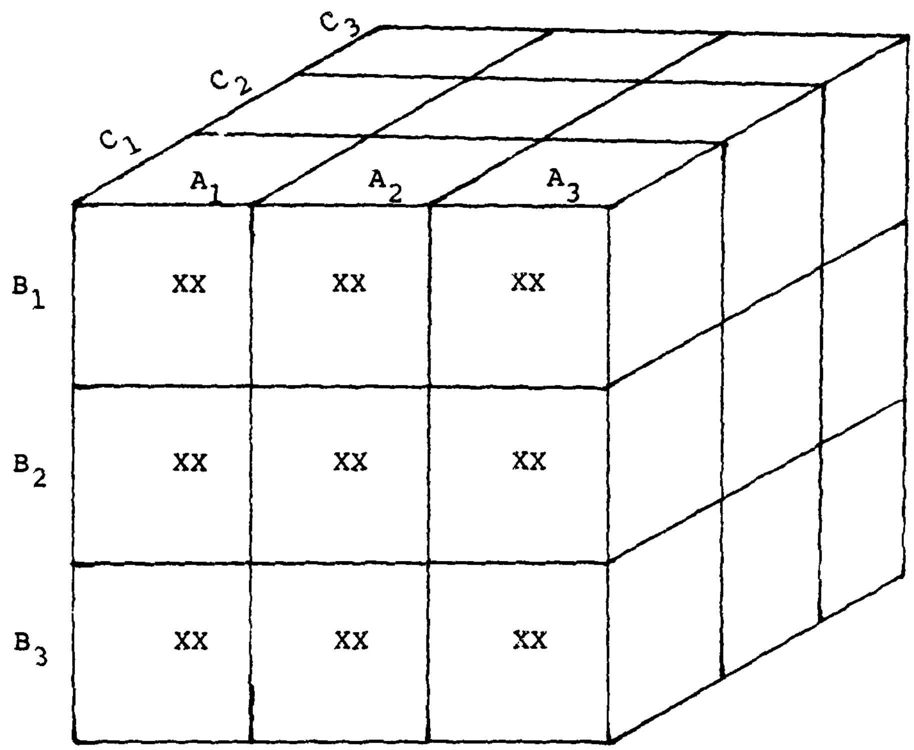


Fig. 8. Representation of Samples within Cells

the model. In other words, only two runs were made with 4 planners, average material lead time, and 0.10 Chief of R&R availability before one of the levels had to be changed.

Three-Factor ANOVA

Once the data was obtained, the SPSS subprogram ANOVA was used to test the factors for significant main effects, two-way interactions, and three-way interactions. The general format for the output for ANOVA is shown in Table 5. A main effect or interaction was considered significant if $F_{TAB} > F_{(1-\alpha,\nu_1,\nu_2)}$.[3] Examples of the tests for interactions and main effects are presented below.

Three-Way Interactions. The test for three-way interactions tests whether or not three factors interact to affect the mean work order processing time. The null and alternate hypotheses for this test are:

> H_0: *The number of planners available, material lead time, and Chief of R&R availability do not interact to influence the mean work order processing time.*
>
> H_1: *The number of planners available, material lead time, and Chief of R&R availability do interact to influence the mean work order processing time.*

---

[3] F_{TAB} was obtained from the last column in Table 5. $F_{(1-\alpha,\nu_1,\nu_2)}$ was obtained from a table of critical values for the F-distribution, where $\alpha = 0.05$ and ν_1 and ν_2 are the numerator and denominator degrees of freedom.

TABLE 5

FORMAT FOR ANOVA TESTS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_{TAB}
Main Effects				
A	XX.XXX	2	X.XXX	X.XXX
B	XX.XXX	2	X.XXX	X.XXX
C	XX.XXX	2	X.XXX	X.XXX
Two-Way Interactions				
AB	XX.XXX	4	X.XXX	X.XXX
AC	XX.XXX	4	X.XXX	X.XXX
BC	XX.XXX	4	X.XXX	X.XXX
Three-Way Interactions				
ABC	XX.XXX	8	X.XXX	X.XXX
Error	XX.XXX	27	X.XXX	-

The critical value of the F statistic to test these hypotheses is $F_{(0.95,8,27)} = 2.31$.

Two-Way Interactions. The test for two-way interactions tests whether or not two factors interact to affect the mean work order processing time. An example of the null and alternate hypotheses for one pair of factors is:

H_0: *The number of planners available and the material lead time do not interact to influence the mean work order processing time.*

H_1: *The number of planners available and the material lead time do interact to influence the mean work order processing time.*

The two other combinations of factors were tested using the same format as the example above. The critical value of the F statistic to test these hypotheses is $F_{(0.95,4,27)} = 2.73$.

Main Effects. The test for main effects tests whether or not the factor level means for one factor are significantly different from one another. It should be noted that if strong interactions exist, the test for main effects may not yield useful results (10:579). An example of the null and alternate hypotheses for a test of main effects is:

H_0: *The mean work order processing times obtained by varying the number of planners available are equal.*

H_1: *The mean work order processing times obtained by varying the number of planners available are not equal.*

The two other factors were tested in a similar manner. The critical value of the F statistic to test these hypotheses is $F_{(0.95,2,27)} = 3.35$.

Tukey Multiple Comparisons

Whenever the mean work order processing times for main effects were not equal or interactions existed, Tukey multiple comparison confidence intervals were developed. Tukey intervals were established using a family confidence coefficient which for this research is 0.95. As an example, for the three-factor ANOVA the general form of the Tukey confidence interval is:

$$\text{LOWER BOUND} \leq \mu_{ijk} - \mu_{i'j'k'}{}^{4} \leq \text{UPPER BOUND}$$

If the confidence interval encompasses zero, then that pair of means is not significantly different from each other. Otherwise, the confidence interval provides the expected difference in work order processing times between a pair of means. For instance, the Tukey confidence interval

$$15.2 \leq \mu_{122} - \mu_{223} \leq 18.0$$

signifies that 95 percent of the time the difference in the mean work order processing times for a system with 4

[4] The indices i, j, k indicate the level of the factor; i represents levels for the number of planners, j represents levels for material lead time, and k represents levels for the Chief of R&R availability.

planners, average material lead time, and 0.10 Chief of R&R availability and a system with 5 planners, average material lead time, and 0.15 Chief of R&R availability will be in the range from 15.2 to 18.0 days.

Assumptions

The following assumptions were made to facilitate the various tests in this research:

1. The 0.05 significance level is adequate for the statistical tests used to satisfy the research objectives.

2. The samples in each cell of the three-factor ANOVA are from normally distributed populations with equal variances. This assumption is further upheld by the fact that the data points are grand means obtained from 30 separate means. Harnett states that a good approximation to the Central Limit Theorem is $n \geq 30$ (8:206).

3. For the three-factor ANOVA, the random error terms are independent and normally distributed with mean zero and variances equal.

Limitations

The following limitations were placed on the research due to time and resource restrictions:

1. The system under study is the work request/ work order system from the receipt of the work request through to work start. The model does not include job

orders, contract work, or self-help work orders. Also, this research does not consider work order start to work order completion because data was not available to model the numerous factors which interact within this portion of the system. This limitation prevents generalization of the model to the entire work processing system.

2. The Q-GERT model used in this research is taken from the research of Arnold and Fogleman. The assumptions they made and the regression equations they used are taken as is, although numerous portions of their model were checked for accuracy.

3. The work request and work order data used to check the model is identical to data used by Arnold and Fogleman to develop their model. Due to time constraints, no new data could be obtained from other bases to replicate their research and aid in externally validating the model.

At this point, it seems important to note a comment made by Arnold and Fogleman because it applies here as well:

> Even though this research was limited, the techniques could be extended both horizontally to include other methods of work accomplishment and vertically to include a representative sample of bases to construct models better suited to one of the possible uses of such a model [1:7].

Having just described the methodology used to satisfy the research objectives, let us now turn to analyzing the results of this research.

CHAPTER IV

ANALYSIS OF RESULTS

Overview

This chapter analyzes the results of the research following the procedures discussed in Chapter III. The results of each research objective are presented separately to avoid confusing the reader. Also discussed are some decision aids derived from these results which may help managers with decision making.

Research Objective Number 1

To verify that the Q-GERT model presented by Arnold and Fogleman, and modified in this research, is still valid according to the procedures used in civil engineering today.

Air Force Regulations 85-10, 85-1, and 86-1 were reviewed to determine whether or not the model of the work request/work order system developed by Arnold and Fogleman was still valid. Since AFRs 85-10 and 86-1 do not deal directly with the work request/work order system, they were only given a cursory review. AFR 85-1, however, provides an in-depth discussion of the processes which make up the work request/work order system. When Arnold and Fogleman modeled the system they used the AFR 85-1 dated 22 September 1978. Very few changes have been made to AFR 85-1

since that time and no changes have been made to the work request/work order system.

This researcher also used his own CE experience and the experience of several other Air Force civil engineers to verify the model. This was accomplished by manually processing a sample work request through the Q-GERT model in order to determine whether: (1) the model followed the work request/work order procedures outlined in AFR 85-1, and (2) the various processing times used by the model were reasonable.

Both the review of Air Force regulations and the manual simulation of the Q-GERT model failed to uncover any flaws in the structure of the model. This resulted in the conclusion that the Q-GERT model of the work request/work order system developed by Arnold and Fogleman is still valid according to the procedures used in civil engineering today.

Research Objective Number 2

To operationalize the model through the use of computer simulation.

The majority of the time spent on this research was spent on operationalizing the model. As indicated previously, the original model from Arnold and Fogleman was lacking several FORTRAN statements which needed to be added in order to obtain any output. With the appropriate

statements added and using the smaller version of the Q-GERT Analysis Program, the next barrier encountered was the same one which stopped Arnold and Fogleman in their thesis: error type 14, "Insufficient space available to store attributes of transactions," necessitating a switch to the larger version of the Q-GERT Analysis Program. This large version's increased memory capacity helped overcome the storage limitation imposed by error type 14.

The simulation of the work request/work order system now produced various reports; however, the output indicated that there was still some fine tuning to be accomplished on the model. For example, the simulation was returning a real value for the number of workdays in a month, say 19.52, while the number of workdays in one week for the same month remained constant at 5. It was not too difficult to see that the number of workdays in the month and week were quickly becoming out of sync. Problems such as this were corrected until reasonable output[1] was obtained. At that point, the model was considered operationalized.

Research Objective Number 3

To internally validate the model.

The Chi-Square goodness of fit test was used to satisfy this objective. The work request and work order

---

[1]Reasonable output was determined by the researcher based on his CE experience and an analysis of the Barksdale data used to develop the model.

data obtained from the simulation to validate the model is shown in Tables 6 and 7 along with the expected frequencies and the χ^2_{TAB} values.

For the work request data, since the χ^2_{TAB} value of 5.26 is less than $\chi^2_{(5,0.05)}$, which is 11.07, the null hypothesis cannot be rejected. In other words, the work request data from the simulation follows the same distribution as the Barksdale work request data.

For the work order data, since the χ^2_{TAB} value of 97.17 is greater than $\chi^2_{(13,0.05)}$, which is 22.36, the null hypothesis can be rejected which means that the work order data from the simulation does not follow the same distribution as the Barksdale work order data.

TABLE 6

WORK REQUEST VALIDATION

Cells	Observed Frequencies (O_i)	Expected Frequencies (E_i)	$\frac{(O_i-E_i)^2}{E_i}$
Work Order	376	356	1.12
Contract	93	82	1.48
Job Order	329	329	0
Disapproved	83	86	0.10
Cancelled	91	98	0.50
Unacceptable	213	235	2.06
	1185	1185	5.26

TABLE 7

WORK ORDER VALIDATION

Cells	Observed Frequencies (O_i)	Expected Frequencies (E_i)	$\frac{(O_i-E_i)^2}{E_i}$
0- 20	0	27	27.80
21- 40	18	30	4.80
41- 60	32	15	19.27
61- 80	35	20	11.25
81-100	24	24	0.00
101-120	25	25	0.00
121-140	18	26	2.46
141-160	25	17	3.76
161-180	17	21	0.76
181-200	19	12	16.00
201-220	13	4	
221-240	12	6	6.00
241-260	9	10	0.10
261-280	6	9	2.25
281-300	7	4	2.72
301-320	1	0	
321-340	1	4	
341-360	1	1	
361-380	0	0	
380-INF	1	9	
	264	264	97.17

The results of these two tests indicate that there is a lack of sufficient evidence to conclude that the model is internally valid. In the next section some possible causes for the large difference in the distributions of the work order data are addressed.

Possible Causes for Difference in Work Order Data

Although data from the work request subsystem of the model seemed to indicate that a good correlation exists between data obtained by simulation and data obtained from Barksdale AFB, data from the work order subsystem of the model did not follow the same distribution as the Barksdale work order data. Three possible causes for this discrepancy are: (1) the regression equations used to estimate key variables may not provide good estimates for these variables, (2) the work order data obtained from Barksdale AFB may not be a representative sample of work orders exiting the system, and (3) the model may not represent how the work request/work order system actually works.

While several independent variables were regressed against each dependent variable to obtain estimates for key processes in the model, many more were not considered due to the unavailability of appropriate data. Therefore, these regression equations had to be used to estimate the variables even though the range of R square values, or the

proportion of variation explained by the independent variables, was only 0.1164 to 0.2950.

Another cause for the difference may be that the work order data acquired from Barksdale AFB by Arnold and Fogleman for the period from 1 March 1977 to 28 February 1979 may not constitute a representative sample of work orders processed through the work request/work order system. During a portion of the time period over which the data was collected Barksdale AFB was serving as a test base for a major organization conversion of the BCE organization. In fact, a major portion of that conversion involved instituting the work request/work order system modeled in this research. Therefore, the Barksdale work order data used in this research might not represent data for a steady-state condition, whereas, data from the model does represent steady-state conditions.

One other cause for the difference might be that this research did not model the work request/work order system as it actually exists. For instance, a command-interest work order might circumvent the established work request/work order system which could result in many work orders traversing the system much faster than normal. If this were the case at Barksdale AFB, the data used by this research would reflect this circumvention which would lead to a difference between the model used in this research and the real world.

Even though there was a lack of evidence to validate the model, it was the feeling of this researcher that the output obtained from the simulation was consistent enough to yield adequate results when testing the model to satisfy research objective number 4.

Research Objective Number 4

To test the model's sensitivity to changes in several factors affecting the mean work order processing time.

The two tests used to satisfy this objective were the three-factor ANOVA and the Tukey method of multiple comparisons.

Three-Factor ANOVA

The results of the three-factor ANOVA are shown on Table 8. Clearly the F_{TAB} value for three-way interactions is less than the critical value of the F statistic, which is 2.31. Therefore, the null hypothesis cannot be rejected and the conclusion is that a three-way interaction does not exist.

For all two-way interactions, the F_{TAB} values are less than the critical value of the F statistic, which is 2.73. Therefore, two-way interactions do not exist.

For main effects, the F_{TAB} values for the number of planners and Chief of R&R availability are less than the critical value of the F statistic, which is 3.35. Thus,

TABLE 8

RESULTS OF THREE-FACTOR ANOVA

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_{TAB}
Main Effects				
A	0.937	2	0.469	0.265
B	8909.242	2	4454.621	2522.131
C	2.794	2	1.397	0.791
Two-Way Interactions				
AB	6.721	4	1.680	0.951
AC	7.057	4	1.764	0.999
BC	15.305	4	3.826	2.166
Three-Way Interactions				
ABC	25.124	8	3.141	1.778
Error	47.688	27	1.766	-

the hypothesis that the mean work order processing times obtained by varying each of these two factors are equal cannot be rejected. The F_{TAB} value for material lead time, however, is greater than the critical value of the F statistic so the conclusion is that the mean work order processing times obtained by varying the material lead time are not equal.

Since the mean work order processing times for the material lead time are significantly different, Tukey confidence intervals were developed for this factor.

Tukey Multiple Comparisons

The Tukey multiple comparison confidence intervals for material lead time are shown in Figure 9.

$$13.30 \leq \mu_{.1.} - \mu_{.2.} \leq 16.22$$
$$15.23 \leq \mu_{.2.} - \mu_{.3.} \leq 18.15$$
$$29.99 \leq \mu_{.1.} - \mu_{.3.} \leq 32.91$$

Fig. 9. Tukey Confidence Intervals

These confidence intervals are useful to the decision maker because they show him/her the range of difference in the mean work order processing times resulting from different levels of the material lead time. For example, if the manager (in this case the Chief of R&R) feels that the material lead time is slow (4/3 avg) compared to the average material lead time, the first interval

in Figure 9 warns him/her to expect the mean work order processing time to increase by 13.30 to 16.22 days.

While the Tukey intervals shown in Figure 9 are instructive, they can be made more useful by displaying them in matrix form as illustrated in the next section.

Decision Aids for Managers

This section presents only two of several decision aids which could be devised using the results from this simulation of the work request/work order system.

The Tukey intervals described earlier could be displayed in a matrix as shown in Figure 10. By using this matrix the Chief of R&R has a quick reference tool which will show him/her what the effect will be on the mean work order processing time if the material lead time varies. For instance, if the material lead time is reduced from avg to 2/3 avg the matrix shows a reduction in the mean work order processing time between 15.23 and 18.15 days.

The second decision aid demonstrates the effect of the interaction of two factors on the mean work order processing time. Although it was concluded that two-way interactions did not exist, let's assume for a moment that a two-way interaction between material lead time and the Chief of R&R availability does exist. Figure 11 is an example of a graphical decision aid which could be devised to provide a quick reference tool to the Chief of R&R.

FROM	4/3 AVG	AVG	2/3 AVG
4/3 AVG		+ (13.30-16.22)	+ (29.99-32.91)
AVG	- (13.30-16.22)		+ (15.23-18.15)
2/3 AVG	- (29.99-32.91)	- (15.23-18.15)	

Fig. 10. Matrix for Material Lead Time

NOTE: (+ and -) indicates that the mean work order processing time will increase/decrease by the amount shown.

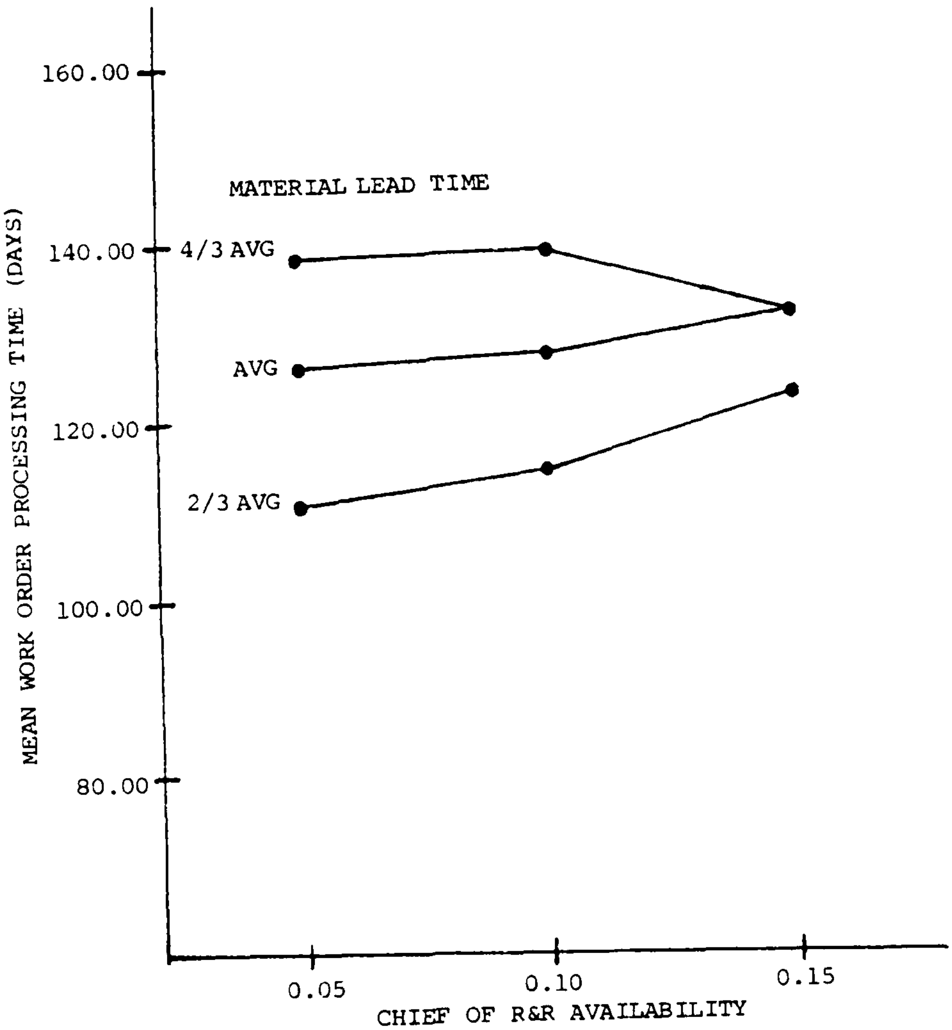


Fig. 11. Graph Showing Effect of Two Factors

For instance, if the Chief of R&R wanted an estimate of the mean work order processing time for 0.10 Chief of R&R availability and fast (2/3 avg) material lead time, from the graph he/she would obtain a mean time of approximately 114 days.

This concludes the analysis of results for this research. In the next chapter, the conclusions and recommendations are presented.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the Research

This research used a modified version of a mathematical model of the work request/work order system developed by Arnold and Fogleman to simulate the real world system. The Arnold and Fogleman model was first checked to verify that it is still valid according to current procedures used in civil engineering to process work orders. After the model was verified, it was operationalized using the Q-GERT Analysis Program.

Next, the work request and work order data obtained from the simulation of the work request/work order system was compared with work request and work order data from Barksdale AFB using the Chi-Square goodness of fit test. These data were compared in order to determine if the model was internally valid. Unfortunately, only the work request subsystem of the model could be validated. However, even though there was a lack of sufficient evidence to conclude that the work order subsystem was internally valid, possible causes for this lack of evidence were presented in Chapter I.

Three factors--the number of planners, the material lead time, and Chief of R&R availability--were varied and

tested to determine their effects, both individually and collectively, on the mean work order processing time. A three-factor ANOVA was used to test the factors, and results showed that only the material lead time had a significant effect on the mean work order processing time. Tukey multiple comparison confidence intervals were developed to determine which levels of the material lead time had a significant effect on the mean work order processing time and the magnitude of the effect.

Finally, this research presented some decision aids which could be devised from the simulation results to aid the Chief of R&R in making decisions. A matrix was presented using the results from the Tukey confidence intervals. Also, a graphical representation showing the effect on the mean work order processing time of the interaction of two factors to demonstrate another decision aid which could be made available to the Chief of R&R. These decision aids are practical, everyday tools which can be used by managers to aid in decision making.

Before the numerous advantages to be gained by using this simulation model of the work request/work order system can be realized, high-level individuals in Air Force Civil Engineering need to, first, become aware of its advantages and, second, make it operational. Hopefully, the practical uses discussed in the next section and the

conclusions drawn from the research are a start toward achieving the first objective.

Conclusions about the Model

Although this model of the work request/work order system needs further testing, this researcher feels that the model can effectively evaluate potential changes to the system, provide better information to managers, and estimate the mean work order processing time for the system. Once the model is validated, and there is little reason to expect that it can't be done, the model would be best utilized within each individual Base Civil Engineering organization. Within each organization data would be immediately available to update parameters within the model.

If the Chief of R&R had this model at base level, he/she could evaluate potential command-initiated or locally-initiated changes to the work request/work order system before committing manpower and resources to the change. The Chief of R&R could also determine what effect certain management decisions might have on the mean work order processing time instead of employing trial and error management techniques. Use of the evaluative and informative capabilities of this model should increase the efficiency and effectiveness of the system, thereby increasing productivity.

This model could also provide the Customer Service Unit with up-to-date estimates of the mean work order processing time to give customers some idea of when work will be started. With this information, customers can better plan related activities around the CE work. This estimative capability of the model seems sure to improve customer satisfaction.

Unfortunately, this model of the work request/work order system is not ready for implementation. Further testing of the model is necessary in order to validate the model and increase its generalizability. Some of these tests are discussed in the next section.

Recommendations

The foremost recommendation of this research is that new data be obtained from another Air Force base, the parameters of the model altered accordingly, and another attempt made to validate the model. Of course, data will need to be obtained from a wide variety of bases before the model can be generalized to be applicable Air Force-wide.

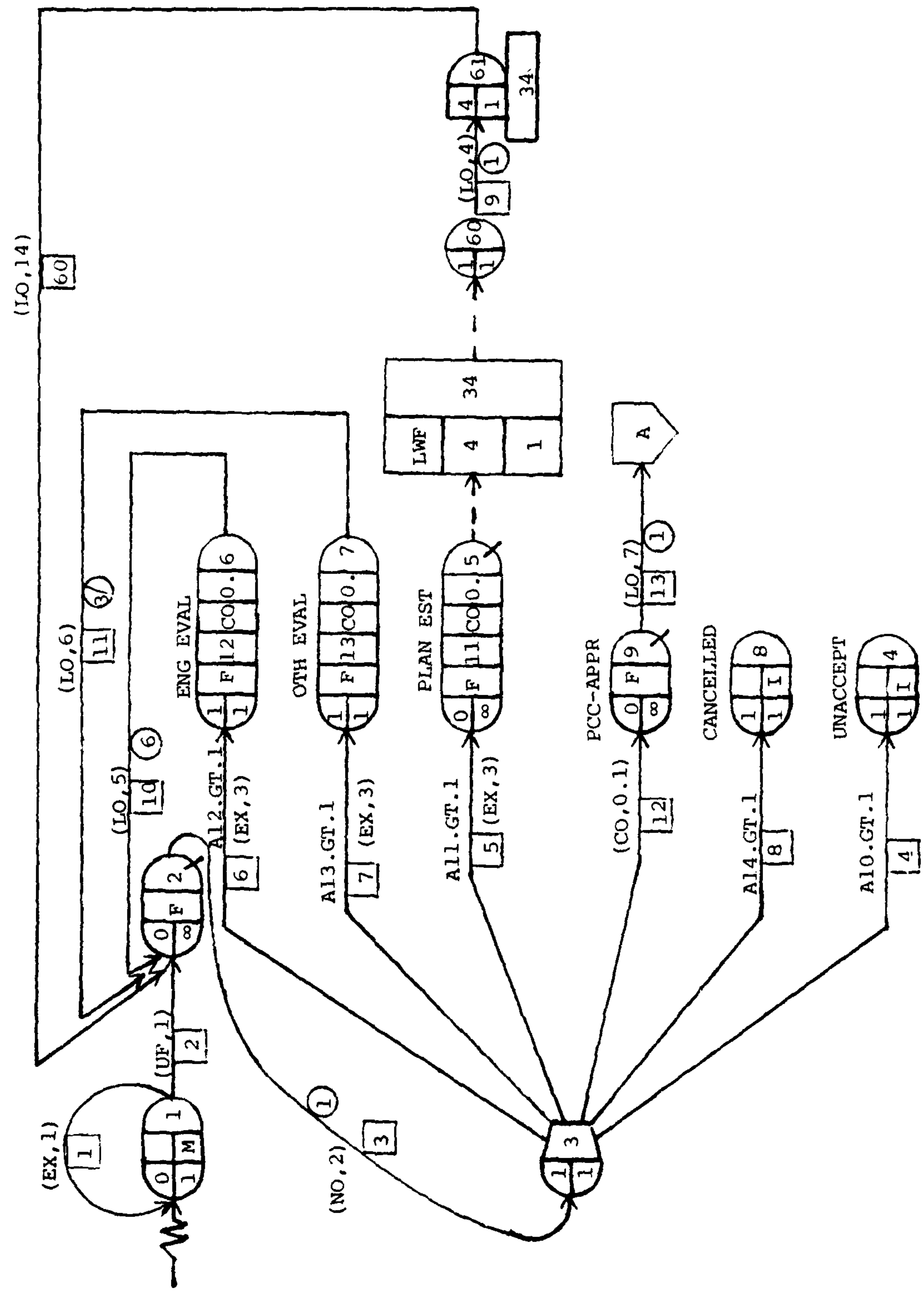
The feasibility of installing such a model at base level needs to be investigated. As part of the investigation, computer costs, computer accessibility, reliability, maintainability, etc. should be considered. Perhaps this model could become part of the Management Information System currently being studied by Air Force Civil Engineering.

Once the model is validated, it should be expanded both horizontally and vertically. It should be expanded horizontally to include the work start-to-work completion portion of the work processing system. It should be expanded vertically to include contract work, job orders, and self-help work orders. This expansion could ultimately lead to a simulation model of the entire civil engineering work accomplishment system.

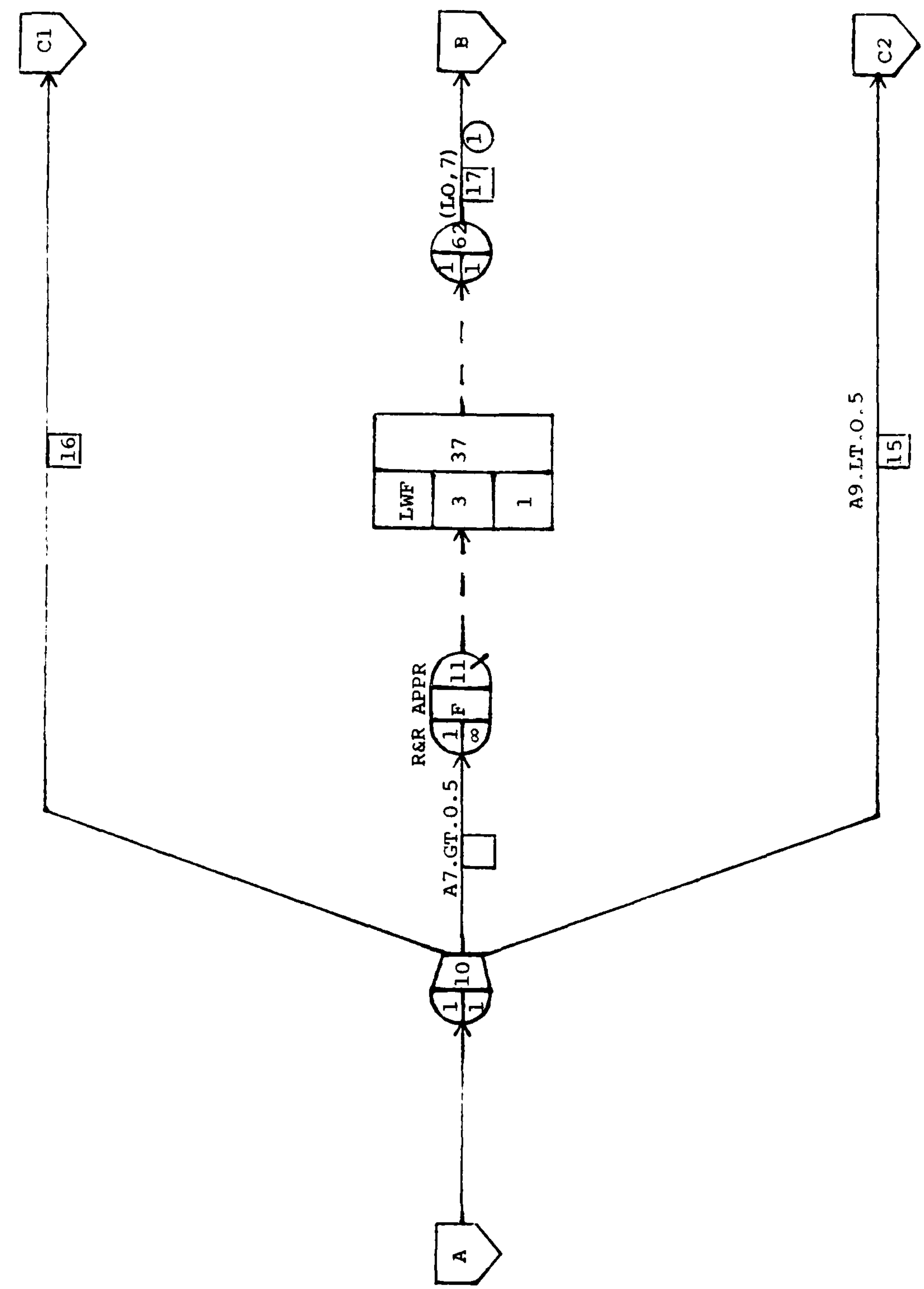
APPENDICES

APPENDIX A

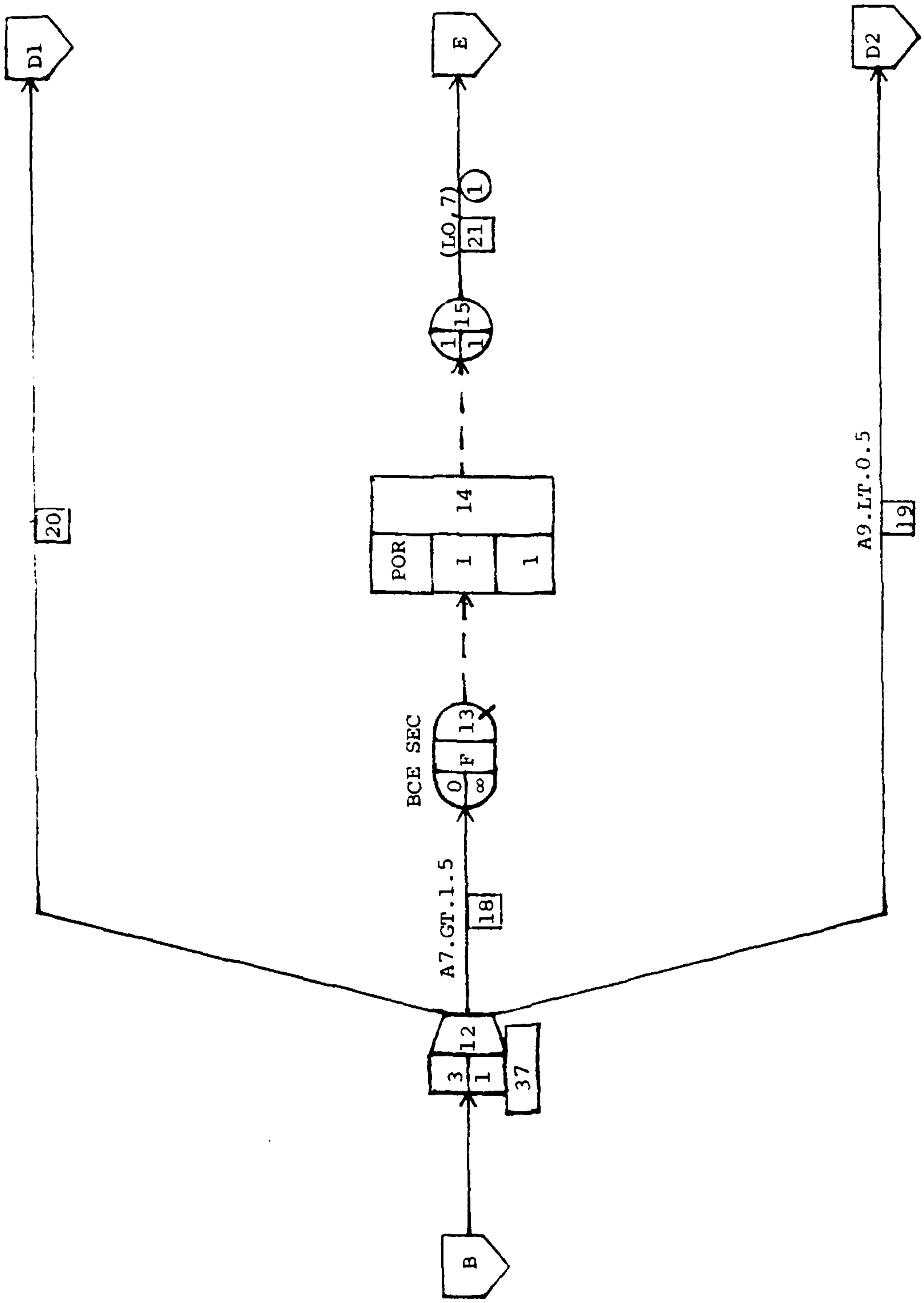
Q-GERT NETWORK MODEL



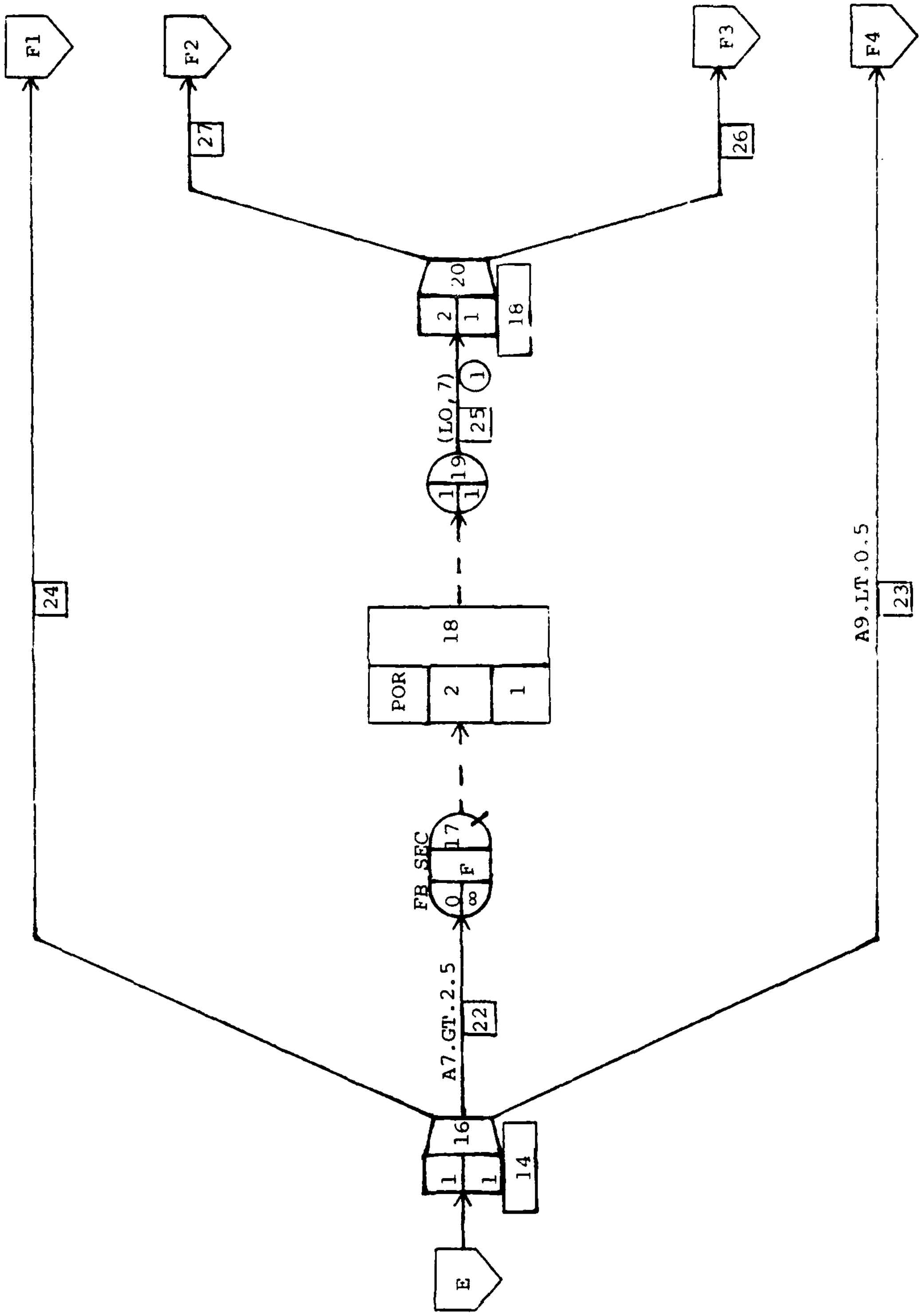
ENG EVAL
OTH EVAL
PLAN EST
PCC-APPR
CANCELLED
UNACCEPT
LWF
A12.GT.1
A13.GT.1
A11.GT.1
A14.GT.1
A10.GT.1
(EX,1)
(UF,1)
(NO,2)
(LO,5)
(LO,6)
(LO,7)
(LO,4)
(LO,14)
(CO,0.1)

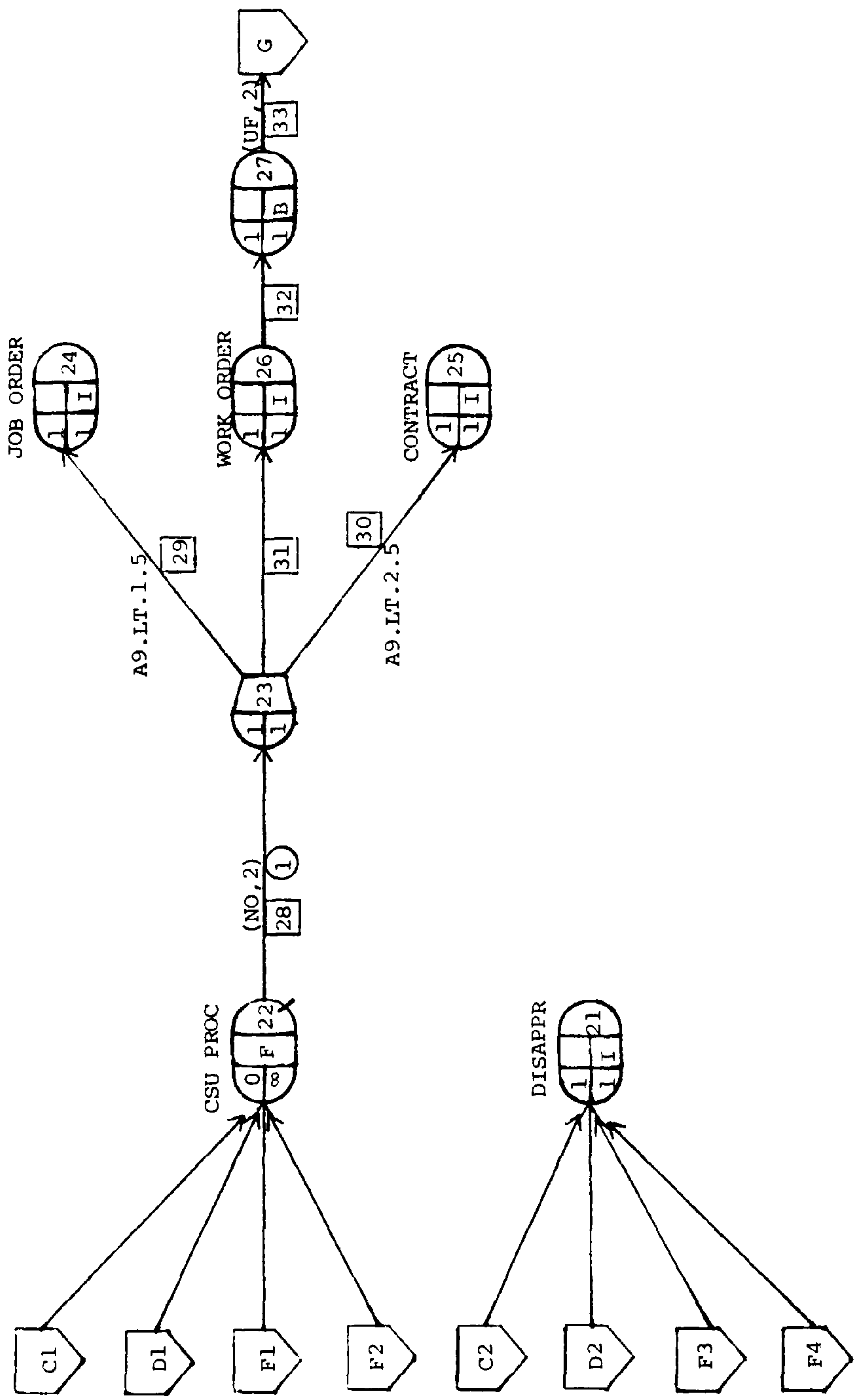


A
1
10
1
A7.GT.0.5
R&R APPR
1
F
11
∞
LWF
3
1
37
1
62
1
(LO,7)
17
1
B
C1
16
C2
A9.LT.0.5
15

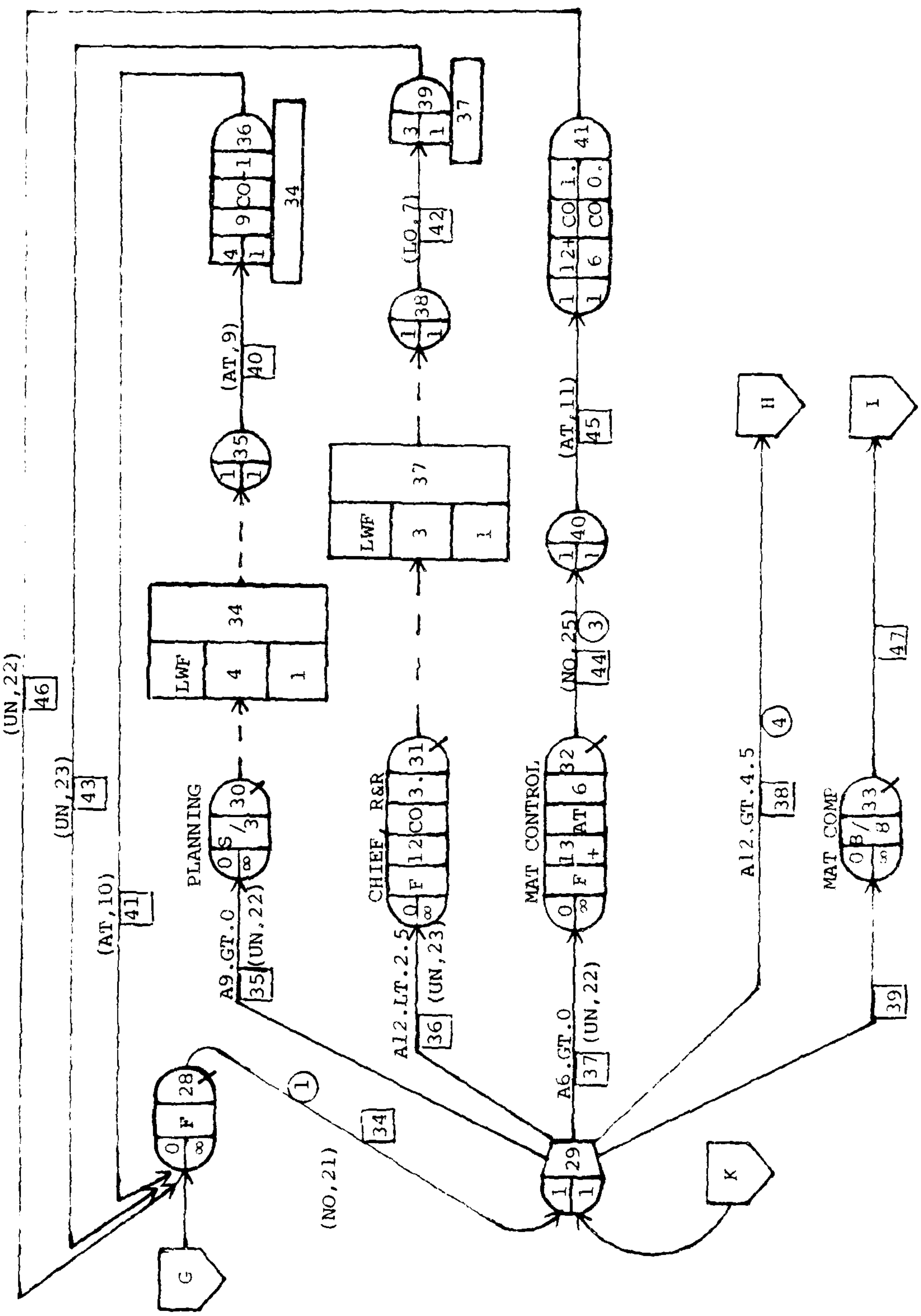


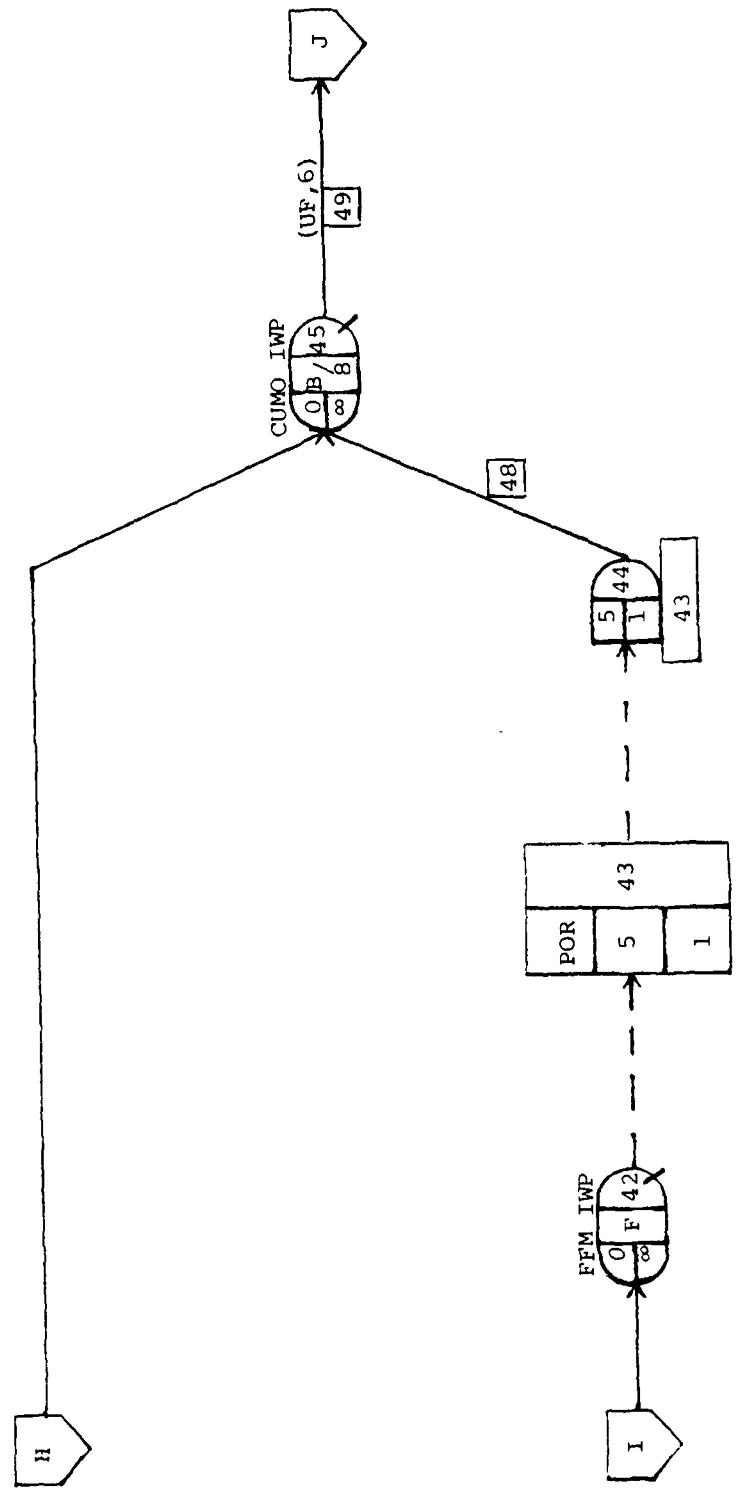
D1
E
D2
(LO,7)
1
21
15
1
1
14
POR
1
1
20
A9.LT.0.5
19
BCE SEC
O
F
13
∞
A7.GT.1.5
18
12
3
1
37
B

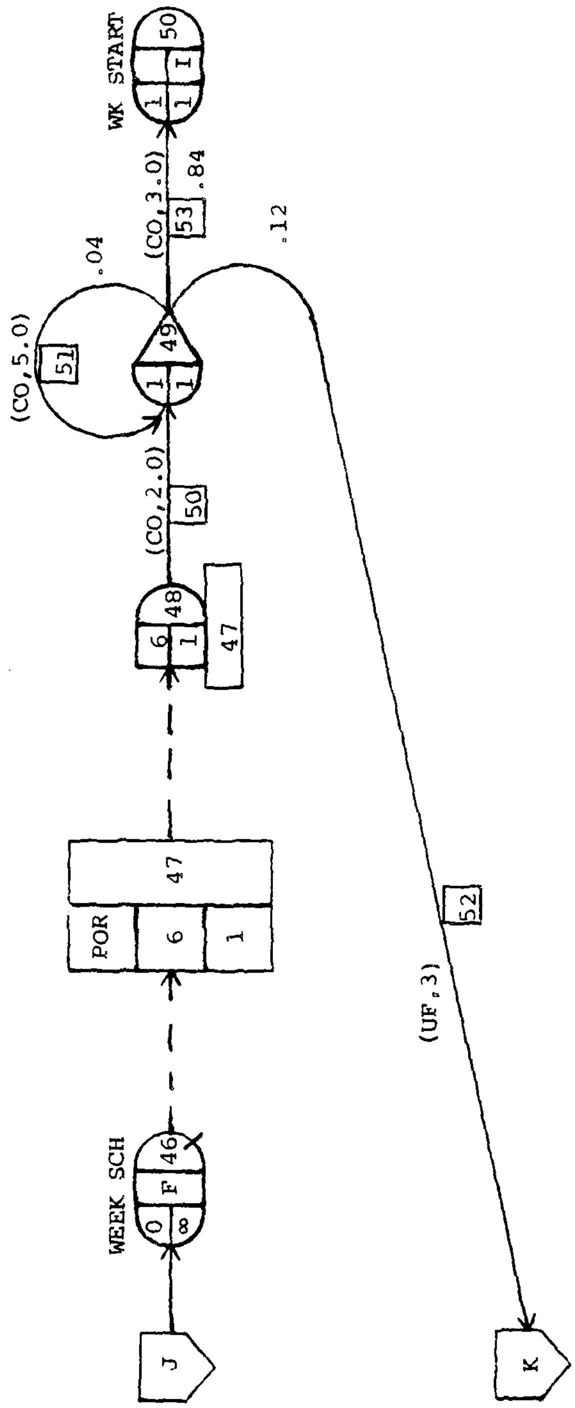

E
1
1
14
16
A7.GT.2.5
22
FB_SEC
0
∞
F
17
POR
2
1
18
1
1
19
(LO,7)
25
1
2
1
18
20
27
26
24
A9.LT.0.5
23
F1
F2
F3
F4

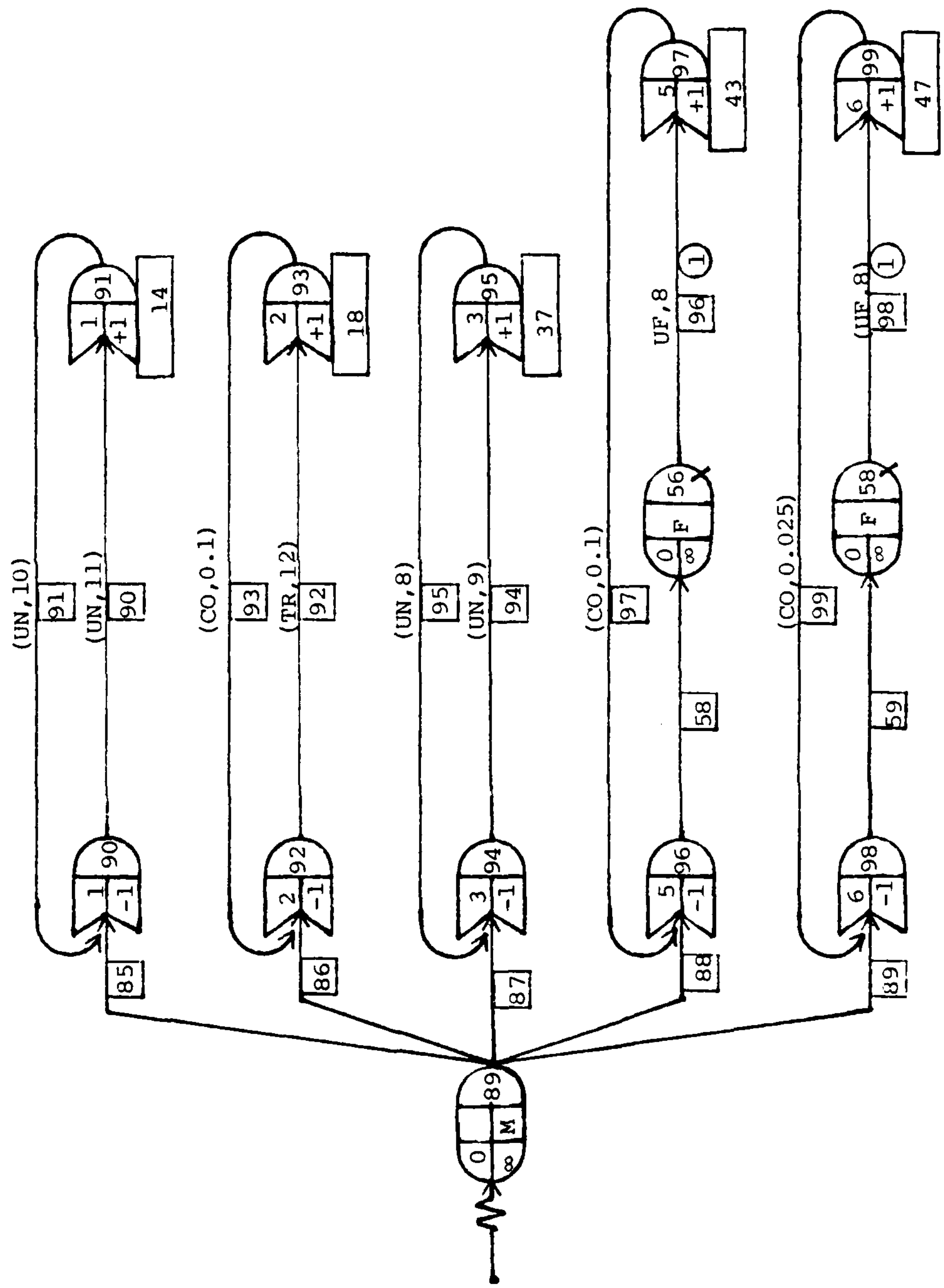


G
(UF,2)
33
27
32
JOB ORDER
24
WORK ORDER
26
CONTRACT
25
A9.LT.1.5
29
31
30
A9.LT.2.5
23
(NO,2)
28
CSU PROC
22
DISAPPR
21
C1
D1
F1
F2
C2
D2
F3
F4


PLANNING
CHIEF R&R
MAT CONTROL
MAT COMP
LWF
A9.GT.0
A12.LT.2.5
A6.GT.0
A12.GT.4.5
(UN,22)
(UN,23)
(AT,10)
(AT,9)
(LO,7)
(AT,11)
(NO,25)
(NO,21)
G
H
I
K


J
(UF,6)
49
CUMO IWP
0
B/45
8
∞
48
5
44
1
43
POR
5
43
1
FFM IWP
0
F
42
∞
H
I


WK START
(CO,3.0)
.84
53
.04
(CO,5.0)
51
.12
(CO,2.0)
50
47
POR
(UF,3)
52
WEEK SCH
J
K


(UN,10)
91
(UN,11)
90
14
(CO,0.1)
93
(TR,12)
92
18
(UN,8)
95
(UN,9)
94
37
(CO,0.1)
97
58
UF,8
96
43
(CO,0.025)
99
59
(UF,8)
98
47
85
86
87
88
89

APPENDIX B

Q-GERT PROGRAM

```
      FUNCTION UF(IFN)
      COMMON /QVAR/ NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),
     :  NRUN,NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
      COMMON/UCOM1/RHR
      DIMENSION ATT(14), K(4)
      REAL NO
C
      GO TO (1,2,3,4,5,6,7,8),IFN
C
    1 UF = 0.0
C
C     *  ASSIGNING VALUES TO ATTRIBUTES 1 TO 13
C
C     **  ATTRIBUTE 1 - WORK CLASS - 0-BLANK 1-MAINT 2-REPAIR
C             3-CONSTRUCTION
C
C     **  ATTRIBUTE 2 - SPECIAL INTEREST CODE - 1-CMD INT 2-FIRE PROT
C             3-HOSP 4-8th AF 5-COMMUN 6-W.S.A. 7-DORM REHAB 8-BOMBCOMP
C
C     **  ATTRIBUTE 3 - PRIORITY
C
C     **  ATTRIBUTE 4 - NUMBER OF SHOPS
C
C     **  ATTRIBUTE 5 - ESTIMATED MANHOURS
C
C     **  ATTRIBUTE 6 - ESTIMATED MATERIALS
C
C     **  ATTRIBUTE 7 - APPROVAL AUTHORITY - 0-PCC 1-R&R 2-BCE
C              3-FB OR HIGHER
C
C     **  ATTRIBUTE 8 - PRECEDENCE
C
C     **  ATTRIBUTE 9 - DISPOSITION - 0-DISAPPROVED 1-JOB ORDER
C             2-CONTRACT 3-WORK ORDER
C
C     **  ATTRIBUTES 10 THRU 14 - WORK REQUEST ROUTING
C             10 - UNACCEPTABLE
C             11 - NEEDS PLANNING EVALUATION
C             12 - NEEDS ENGINEERING EVALUATION
C             13 - NEEDS OTHER EVALUATION
C             14 - SENT BACK OR CANCELLED AFTER EVALUATIONS
      R1 = RANF()
      R2 = RANF()
      R3 = RANF()
      R4 = RANF()
```

```
      K(1) = 0
      K(2) = 0
      K(3) = 1
      K(4) = 1
      IF (TNOW.GT.0.0) GO TO 84
      AHR = 0.0
      BHR = 0.0
   84 IF (R2.LT.0.638) GO TO 10
      IF (R2.LT.0.801) GO TO 14
      IF (R2.LT.0.863) GO TO 18
      IF (R2.LT.0.910) GO TO 21
      IF (R2.LT.0.926) GO TO 24
      IF (R2.LT.0.953) GO TO 25
      IF (R2.LT.0.984) GO TO 27
      IF (R2.LT.0.992) GO TO 29
      K(1) = 3
      K(2) = 8
      IF (R4.GT.0.5) K(4) = 2
      GO TO 30
   10 IF (R1.GT.0.516) GO TO 13
      IF (R1.GT.0.342) GO TO 12
      IF (R1.GT.0.110) GO TO 11
      K(3) = 2
      IF (R3.GT.0.294) K(3) = 3
      IF (R3.GT.0.941) K(3) = 4
      IF (R4.GT.0.278) K(4) = 2
      IF (R4.GT.0.611) K(4) = 3
      IF (R4.GT.0.667) K(4) = 4
      IF (R4.GT.0.944) K(4) = 5
      GOTO 30
   11 K(1) = 1
      K(3) = 2
      IF (R3.GT.0.222) K(3) = 3
      IF (R3.GT.0.944) K(3) = 4
      IF (R4.GT.0.243) K(4) = 2
      IF (R4.GT.0.675) K(4) = 3
      IF (R4.GT.0.756) K(4) = 4
      IF (R4.GT.0.864) K(4) = 5
      IF (R4.GT.0.891) K(4) = 6
      IF (R4.GT.0.945) K(4) = 7
      GOTO 30
   12 K(1) = 2
      IF (R3.GT.0.148) K(3) = 2
      IF (R3.GT.0.629) K(3) = 3
      IF (R4.GT.0.259) K(4) = 2
      IF (R4.GT.0.592) K(4) = 3
      IF (R4.GT.0.888) K(4) = 4
      IF (R4.GT.0.925) K(4) = 5
      IF (R4.GT.0.962) K(4) = 6
      GOTO 30
```

```
13 K(1) = 3
   IF (R3.GT.0.040) K(3) = 2
   IF (R3.GT.0.707) K(3) = 3
   IF (R3.GT.0.880) K(3) = 4
   IF (R4.GT.0.317) K(4) = 2
   IF (R4.GT.0.512) K(4) = 3
   IF (R4.GT.0.756) K(4) = 4
   IF (R4.GT.0.878) K(4) = 5
   IF (R4.GT.0.927) K(4) = 6
   IF (R4.GT.0.964) K(4) = 7
   GOTO 30
14 K(2) = 1
   IF (R1.GT.0.486) GO TO 17
   IF (R1.GT.0.257) GO TO 16
   IF (R1.GT.0.057) GO TO 15
   K(3) = 4
   K(4) = 3
   IF (R4.GT.0.667) K(4) = 5
   GOTO 30
15 K(1) = 1
   K(3) = 2
   IF (R3.GT.0.143) K(3) = 3
   IF (R3.GT.0.572) K(3) = 4
   K(4) = 2
   IF (R4.GT.0.143) K(4) = 3
   IF (R4.GT.0.429) K(4) = 4
   IF (R4.GT.0.858) K(4) = 5
   GOTO 30
16 K(1) = 2
   K(3) = 2
   IF (R3.GT.0.125) K(3) = 3
   IF (R3.GT.0.625) K(3) = 4
   K(4) = 2
   IF (R4.GT.0.111) K(4) = 3
   IF (R4.GT.0.555) K(4) = 4
   IF (R4.GT.0.888) K(4) = 6
   GOTO 30
17 K(1) = 3
   K(3) = 2
   IF (R3.GT.0.389) K(3) = 3
   IF (R3.GT.0.611) K(3) = 4
   IF (R4.GT.0.304) K(4) = 2
   IF (R4.GT.0.434) K(4) = 3
   IF (R4.GT.0.651) K(4) = 4
   IF (R4.GT.0.694) K(4) = 5
   IF (R4.GT.0.911) K(4) = 6
   GOTO 30
18 K(2) = 2
   IF (R1.GT.0.375) GO TO 20
   IF (R1.GT.0.250) GO TO 19
```

```
   K(1) = 1
   K(3) = 2
   IF (R3.GT.0.750) K(3) = 3
   IF (R4.GT.0.500) K(4) = 2
   GOTO 30
19 K(1) = 2
   L(3) = 2
   GOTO 30
20 K(1) = 3
   K(3) = 2
   IF (R4.GT.0.50) K(4) = 2
   IF (R4.GT.0.70) K(4) = 3
   IF (R4.GT.0.90) K(4) = 4
   GOTO 30
21 K(2) = 3
   IF (R1.GT.0.8) GO TO 23
   IF (R1.GT.0.4) GO TO 22
   K(3) = 2
   IF (R3.GT.0.750) K(3) = 3
   IF (R4.GT.0.333) K(4) = 2
   IF (R4.GT.0.667) K(4) = 4
   IF (R4.GT.0.833) K(4) = 5
   GOTO 30
22 K(1) = 1
   K(3) = 3
   IF (R4.GT.0.50) K(4) = 3
   IF (R5.GT.0.75) K(4) = 5
   GOTO 30
23 K(1) = 3
   K(3) = 2
   IF (R3.GT.0.5) K(3) = 4
   K(4) = 2
   IF (R4.GT.0.5) K(4) = 3
   GOTO 30
24 K(1) = 1
   K(2) = 4
   K(3) = 2
   IF (R3.GT.0.25) K(3) = 3
   IF (R4.GT.0.50) K(4) = 2
   IF (R4.GT.0.75) K(4) = 3
   GOTO 30
25 K(2) = 5
   IF (R1.GT.0.25) GO TO 26
   K(1) = 1
   K(3) = 2
   GOTO 30
26 K(1) = 3
   K(3) = 2
   IF (R3.GT.0.667) K(3) = 3
```

```
      IF (R4.GT.0.2) K(4) = 2
      IF (R4.GT.0.4) K(4) = 3
      IF (R4.GT.0.6) K(4) = 6
      IF (R4.GT.0.8) K(4) = 7
      GOTO 30
   27 K(2) = 6
      IF (R1.GT.0.167) GO TO 28
      K(1) = 1
      K(3) = 3
      K(4) = 4
      GO TO 30
   28 K(1) = 3
      K(3) = 2
      K(4) = 2
      IF (R4.GT.0.143) K(4) = 3
      IF (R4.GT.0.714) K(4) = 4
      IF (R4.GT.0.857) K(4) = 6
      GO TO 30
   29 K(1) = 3
      K(2) = 7
      K(3) = 2
      IF (R3.GT.0.5) K(3) = 3
      IF (R4.GT.0.5) K(4) = 3
   30 DO 31 I=1,4
      ATT(I) = FLOAT(K(I))
   31 CONTINUE
      WC = 0.0
      SI = 0.0
      IF (K(1).EQ.1) WC = 40.8196
      IF (K(1).EQ.2) WC = 97.2647
      IF (K(2).EQ.1) SI = 89.4413
      IF (K(2).EQ.4) SI = 111.4747
      IF (K(2).EQ.5) SI = 68.7316
      IF (K(2).EQ.6) SI = 91.9906
      IF (K(2).EQ.8) SI = 141.4610
   32 ATT(5) = ATT(4)*36.8495 + WC + SI - 6.3595 + NO(15)
      IF (ATT(5).LE.8.0) GO TO 32
      WC = 0.0
      SI = 0.0
      IF (K(1).EQ.1) WC = 863.3730
      IF (K(1).EQ.2) WC = 434.8407
      IF (K(2).EQ.1) SI = -344.6478
      IF (K(2).EQ.4) SI = -1773.1925
      ATT(6) = ATT(5)*6.0976 - ATT(4)*185.8713 + WC + SI + 475.9245 +
     :   NO(16)
      IF (ATT(6).LT.0.0) ATT(6) = 0.0
      ATT(7) = 0.0
      ESTCT = ATT(5)*12.67 + ATT(6)
      IF (K(1).EQ.3) GO TO 35
      IF (K(1).EQ.2) GO TO 34
```

```
      IF (K(1).EQ.1) GO TO 33
      IF (ESTCT.GE.10000.) ATT(7) = 1.0
      IF (ESTCT.GE.50000.) ATT(7) = 2.0
      GO TO 36
   33 IF (ESTCT.GE.25000.) ATT(7) = 2.0
      IF (ESTCT.GE.100000.) ATT(7) = 3.0
      GO TO 36
   34 IF (ESTCT.GE.25000.) ATT(7) = 2.0
      IF (ESTCT.GE.50000.) ATT(7) = 3.0
      GO TO 36
   35 IF (ESTCT.GE.2500.) ATT(7) = 1.0
      IF (ESTCT.GE.10000.) ATT(7) = 2.0
      IF (ESTCT.GE.25000.) ATT(7) = 3.0
   36 WC = 0.0
      SI = 0.0
      PR = 0.0
      IF (K(1).EQ.1) WC = 15.0425
      IF (K(1).EQ.2) WC = 21.4988
      IF (K(1).EQ.3) WC = 24.0900
      IF (K(2).EQ.1) SI = -16.3056
      IF (K(2).EQ.5) SI = 70.9451
      IF (K(3).EQ.3) PR = 22.0761
      ATT(8) = 1000.0/(ATT(5)*0.05852 - ATT(6)*0.001928 + WC + SI +
     :   PR + 9.2613 + NO(17))
      R = RANF()
      ATT(9) = 0.0
      IF (R.GE.0.101) ATT(9) = 1.0
      IF (R.GE.0.487) ATT(9) = 2.0
      IF (R.GE.0.582) ATT(9) = 3.0
      DO 37 I=10,14
      ATT(I) = 0.0
   37 CONTINUE
      R = RANF()
      IF (R.LE.0.198) ATT(10) = 2.0
      R = RANF()
      IF (K(1).EQ.3) GO TO 38
      IF (R.LE.0.21) ATT(11) = 2.0
      GO TO 39
   38 IF (R.LE.0.890) ATT(11) = 2.0
   39 R = RANF()
      IF (R.LE.0.0614) ATT(12) = 2.0
      R = RANF()
      IF (R.LE.0.01172) ATT(13) = 2.0
      R = RANF()
      IF (R.LE.0.08265) ATT(14) = 2.0
      CALL PUTAT(ATT)
      RETURN
C
C     *  ASSIGNING VALUES TO ATTRIBUTES 9 THRU 13
C
```

```
C       **  ATTRIBUTE 9 - PLANNING MANDAYS
C
C       **  ATTRIBUTE 10 - OTHER PLANNING DELAY
C
C       **  ATTRIBUTE 11 - MATERIAL LEADTIME
C
C       **  ATTRIBUTE 12 - WORK ORDER ROUTING INDICATOR
C
C       **  ATTRIBUTE 13 - ACTUAL MATERIALS-INITIALIZED TO ZERO
C
      2 CALL GETAT(ATT)
        UF = 0.0
        DO 40 I=9,14
        ATT(I) = 0.0
     40 CONTINUE
        DO 41 I=1,4
        K(I) = IFIX(ATT(I) + 0.2)
     41 CONTINUE
        SI = 0.0
        WC = 0.0
        PR = 0.0
        IF (K(1).EQ.1) WC = -0.3366
        IF (K(2).EQ.6) SI = 0.7448
        IF (K(2).EQ.8) SI = -1.7235
        IF (K(3).EQ.1) PR = 1.5596
        IF (K(3).EQ.2) PR = -0.2977
        IF (K(3).EQ.3) PR = -0.4443
        IF (K(3).EQ.4) PR = -0.5476
        ATT(9) = ATT(4)*0.06634 + ATT(5)*0.000775 + WC + SI + PR +
     :    0.9173 + NO(18)
        IF (ATT(9).LT.0.0) ATT(9) = 0.0
        WC = 0.0
        SI = 0.0
        PR = 0.0
        IF (K(1).EQ.3) WC = -2.9921
        IF (K(2).EQ.1) SI = 3.3375
        IF (K(2).EQ.7) SI = 69.691
        IF (K(3).EQ.2) PR = 4.4593
        ATT(10) = ATT(9)*2.6297 + WC + SI + PR + 3.0417 + NO(19)
        IF (ATT(10).LT.0.0) ATT(10) = 0.0
     42 IF (K(1).EQ.1) WC = -10.2961
        IF (K(1).EQ.2) WC = 38.6771
        IF (K(1).EQ.3) WC = 20.8784
        IF (K(2).EQ.1) SI = -36.7407
        IF (K(2).EQ.2) SI = 19.4910
        IF (K(2).EQ.3) SI = -21.5572
        IF (K(2).EQ.5) SI = -50.4506
        IF (K(3).EQ.1) PR = -87.2948
        IF (K(3).EQ.2) PR = -38.8464
```

```
      IF (K(3).EQ.3) PR = -27.9634
      IF (K(3).EQ.4) PR = -44.1655
   59 ATT(11) = ATT(4)*2.8997 + ATT(6)*0.0041 + WC + SI + PR +
     :   87.1651 + NO(20)
      IF (ATT(11).LT.1.0) ATT(11) = 1.0
      IF (ATT(6).EQ.0.0) ATT(11) = 1.0
      IF (IFN.EQ.3) GO TO 61
      CALL PATRB(ATT(9),9)
      CALL PATRB(ATT(10),10)
      CALL PATRB(ATT(11),11)
      CALL PATRB(ATT(12),12)
      CALL PATRB(ATT(13),13)
      CALL PATRB(ATT(14),14)
      RETURN
C
C     *  ASSIGNING NEW VALUES TO ATTRIBUTES 6 AND 11
C
C     **  ATTRIBUTE 6 - ESTIMATED MATERIALS
C
C     **  ATTRIBUTE 11 - MATERIAL LEADTIME
C
    3 UF = 0.0
      CALL GETAT(ATT)
      ATT(6) = TR(24)
      DO 60 I=1,4
      K(I) = IFIX(ATT(I) + 0.2)
   60 CONTINUE
      GO TO 42
   61 ATT(12) = 5.0
      CALL PATRB(ATT(6),6)
      CALL PATRB(ATT(11),11)
      CALL PATRB(ATT(12),12)
      RETURN
C
C     *  DETERMINING WHETHER THE FIRST FUTURE MONTH IS FULL YET.
C
    4 UF = 1.0
      AHR = GATRB(5) + AHR
      RHR = 2000. - AHR
      IF (RHR.LE.0.0) THEN
        UF = REMST (96) + 0.1
        WOMHR = GATRB(5)
      ENDIF
      RETURN
C
C     *  UNFILLING THE FIRST FUTURE MONTH IWP.
C
    5 UF = 0.0
      IF (RHR.GT.0.0) WOMHR = 0.0
```

```
      AHR = WOMHR
      RETURN
C
C     *  DETERMINING WHETHER NEXT WEEKS SCHEDULE IS FULL YET.
C
    6 UF = 0.1
      BHR = GATRB(5) + BHR
      RHR = 500. - BHR
      IF (RHR.LE.0.0) THEN
        UF = REMST(98) + 0.025
        WWOMHR = GATRB(5)
      ENDIF
      RETURN
C
C     *  UNFILLING NEXT WEEKS SCHEDULE TO THE SHOPS
C
    7 UF = 0.0
      IF (RHR.GT.0.0) WWOMHR = 0.0
      BHR = WWOMHR
      RETURN
    * IF (NACTY().EQ.96) THEN
         MONTH = UN(12)
         UF = MONTH
      ENDIF
      IF (NACTY().EQ.98) UF  =  MONTH/4.0
      RETURN
      END


      SUBROUTINE UI
      COMMON/QVAR/NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),
     :  NRUN,NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
      COMMON/UCOM1/RHR
      RHR = 1.0
C
C     *   ENSURE NEW RANDOM NUMBER SEED IS INITIATED
C         FOR EVERY 30 RUNS.
C
      IF(NRUN.GT.1) RETURN
      CALL TIME(A)
      DECODE(201,211,A) IH,IM,IS
201   FORMAT(A10)
211   FORMAT (3(1X,I2),1X)
      N=IH*10000 + IM*100 + IS
      CALL RANSET(N)
      CALL CPTR(24)
      RETURN
      END
```

```
GEN,ST.GELAIS,W.R.-W.O.MOD,6,16,1981,8,,,704.,5,E,200.,14*
SOU,1,0,1,D,M*
QUE,2/CSU COOR,0.,D,F*
REG,3,1,1,F*
STA,4/UNACCEPT,1,1,D,I*
QUE,5/PLAN EST,0,,D,F,(10)34*
REG,60,1,1,D*
FRE,61,D,4,1,34*
REG,6,1,1,D*
REG,7,1,1,D*
STA,8/CANCELED,1,1,D,I*
QUE,9/PCC APPR,0,,D,F*
REG,10,1,1,F*
QUE,11/R&R APPR,0,,D,F,(10)37*
REG,62,1,1,D*
FRE,12,F,3,1,37*
QUE,13/BCE SEC,0,,D,F,(10)14*
ALL,14,,1,1,13/15*
REG,15,1,1,D*
FRE,16,F,1,1,14*
QUE,17/FB SEC,0,,D,F,(10)18*
ALL,18,,2,1,17/19*
REG,19,1,1,D*
FRE,20,F,2,1,18*
STA,21/DISAPPR,1,1,D,I*
QUE,22/CSU PROC,0,,D,F*
REG,23,1,1,F*
STA,24/JOB ORDR,1,1,D,I*
STA,25/CONTRACT,1,1,D,I*
STA,26/WORK ORD,1,1,D,I*
STA,27/WO INTERA,1,1,D,B*
QUE,28/IWP PGMR,0,,D,F*
REG,29,1,1,F*
QUE,30/PLAN PLN,0,,D,S/3,(10)34*
QUE,31/R&R AUTH,0,,D,F,(10)37*
QUE,32/MAT CONT,0,,D,F*
QUE,33/MAT COMP,0,,D,B/8*
ALL,34,LWF,4,1,30/35,5/60*
REG,35,1,1,D*
FRE,36,D,4,1,34*
ALL,37,LWF,3,1,31/38,11/62*
REG,38,1,1,D*
FRE,39,D,3,1,37*
REG,40,1,1,D*
REG,41,1,1,D*
QUE,42/FFM IWP,0,,D,F,(10)43*
ALL,43,,5,1,42/44*
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AD-A110 975 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 13/2
A SIMULATION OF THE BASE CIVIL ENGINEERING WORK REQUEST/WORK OR--ETC(U)
SEP 81 E C ST. GELAIS
UNCLASSIFIED AFIT-LSSR-94-81 NL

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A110975

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FRE,44,D,5,1,43*
QUE,45/CUMO IWP,0,,D,B/8*
QUE,46/WEEK SCH,0,,D,F,(10)47*
ALL,47,,6,1,46/48*
FRE,48,D,6,1,47*
REG,49,1,1,P*
STA,50/WK STRT,1,1,D,I,20.,20.*
QUE,56,0,,D,F*
QUE,58,0,,D,F*
ACT,1,1,EX,1,1*
ACT,1,2,UF,1,2*
ACT,2,3,NO,2,3/CSU PROC,1*
ACT,3,4,,,4,,1,A10.GT.1.*
ACT,3,5,EX,3,5,,2,A11.GT.1.*
ACT,3,6,EX,3,6,,3,A12.GT.1.*
ACT,3,7,EX,3,7,,4,A13.GT.1.*
ACT,3,8,,,8,,5,A14.GT.1.*
ACT,60,61,LO,4,9/PLAN EST*
ACT,61,2,LO,14,60*
ACT,6,2,LO,5,10/ENG EVAL,6*
ACT,7,2,LO,6,11/OTH EVAL,6*
ACT,3,9,CO,0.1,12,,6*
ACT,9,10,LO,7,13/PCC APPR,1*
ACT,10,11,,,14,,1,A7.GT.0.5*
ACT,10,21,,,15,,2,A9.LT.0.5*
ACT,10,22,,,16,,3*
ACT,62,12,LO,7,17/R&R APPR,1*
ACT,12,13,,,18,,1,A7.GT.1.5*
ACT,12,21,,,19,,2,A9.LT.0.5*
ACT,12,22,,,20,,3*
ACT,15,16,LO,7,21/BCE,1*
ACT,16,17,,,22,,1,A7.GT.2.5*
ACT,16,21,,,23,,2,A9.LT.0.5*
ACT,16,22,,,24,,3*
ACT,19,20,LO,7,25/FB,1*
ACT,20,21,,,26,,1,A9.LT.0.5*
ACT,20,22,,,27,,2*
ACT,22,23,NO,2,28/CSU CHAN,1*
ACT,23,24,,,29,,1,A9.LT.1.5*
ACT,23,25,,,30,,2,A9.LT.2.5*
ACT,23,26,,,31,,3*
ACT,26,27,,,32*
ACT,27,28,UF,2,33*
ACT,28,29,NO,21,34/PGMR PRO,1*
ACT,29,30,UN,22,35,,1,A9.GT.0.*
ACT,29,31,UN,23,36,,2,A12.LT.2.5*
ACT,29,32,UN,22,37,,3,A6.GT.0.0*
ACT,29,45,,,38,4,4,A12.GT.4.5*
ACT,29,33,,,39,,5*
ACT,35,36,AT,9,40*
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ACT,36,28,AT,10,41*
ACT,38,39,LO,7,42*
ACT,39,28,UN,23,43*
ACT,32,40,NO,25,44/M-C PROC,3*
ACT,40,41,AT,11,45*
ACT,41,28,UN,22,46*
ACT,33,42,UF,4,47/PGM MO,1*
ACT,44,45,,,48*
ACT,45,46,UF,6,49/SCH WEEK,1*
ACT,48,49,CO,2.0,50*
ACT,49,49,CO,5.0,51,,0.04*
ACT,49,28,UF,3,52,,0.12*
ACT,49,50,CO,3.0,53,,0.84*
SOU,89*
ALT,90,D,1,-1*
ALT,91,D,1,1,14*
ALT,92,D,2,-1*
ALT,93,D,2,1,18*
ALT,94,D,3,-1*
ALT,95,D,3,1,37*
ALT,96,D,5,-1*
ALT,97,D,5,1,43*
ALT,98,D,6,-1*
ALT,99,D,6,1,47*
ACT,89,90,,,85*
ACT,89,92,,,86*
ACT,89,94,,,87*
ACT,89,96,,,88*
ACT,89,98,,,89*
ACT,90,91,UN,11,90*
ACT,91,90,UN,10,91*
ACT,92,93,TR,13,92*
ACT,93,92,CO,0.1,93*
ACT,94,95,UN,9,94*
ACT,95,94,UN,8,95*
ACT,96,56,,,58*
ACT,56,97,UF,8,96,1*
ACT,97,96,CO,0.1,97*
ACT,98,58,,,59*
ACT,58.99,UF,8,98,1*
ACT,99.98,CO,0.025,99*
VAS,5,11,CO,0.0*
VAS,6,12,CO,0.0*
VAS,7,13,CO,0.0*
VAS,36,9,CO,-1.0*
VAS,31,12,CO,3.0*
VAS,32,13+,AT,6*
VAS,41,12+,CO,1.0,6,CO,0.*
VAS,96,14,UF,5*
VAS,98,14,UF,7*
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RES,1/BCE,1,14*
RES,2/FAC BD,1,18*
RES,3/R&R CH,1,37*
RES,4/PLANNERS,6,34*
RES,5/MO PROG,1,43*
RES,6/MO SCHED,1,47*
PAR,1,0.412,0.0*
PAR,2,.05,0.,,.01*                  CSU PROCESSING TIME
PAR,3,1.,0*                         DELAY TO PLAN, DEE & OTHER
PAR,4,0.482,0.0,,0.435*             PLAN EST TIME
PAR,5,33.417,0.0,,48.25*            DEE EVAL TIME
PAR,6,2.,0.0,,1.*                   OTHER EVAL TIME
PAR,7,0.01,0.0,,0.1*                APPROVAL & AUTH TIME
PAR,8,,0.01,0.1*                    R & R AVAILABLE
PAR,9,,0.0,0.5*                     R & R NON-AVAILABILITY
PAR,10,,0.0,0.02*                   BCE AVAILABLE
PAR,11,,0.5,1.5*                    BCE NON-AVAILABLE
PAR,12,,19.0,23.0*                  MO. PROG FREQ
PAR,13,21.0,19.0,23.0*              FB NON-AVAIL
PAR,14,2.78,0.0,,5.884*             OTHER PLAN EVAL DELAY
PAR,15,0.0,,,127.55*                EST MH FLUC
PAR,16,0.0,,,1894.53*               EST MATL FLUC
PAR,17,0.0,,,48.8*                  PRECEDENCE FLUC
PAR,18,0.0,,,0.8596*                PLANNING MH FLUC
PAR,19,0.0,,,14.333*                OTH PLAN DELAY FLUC
PAR,20,0.0,,,54.83*                 MATL LEADTIME FLUC
PAR,21,0.05,,,0.01*                 PGMR PROC
PAR,22,,0.001,0.5*                  TIME TO PLN & TO & FM M.C.
PAR,23,,0.001,0.2*                  TIME TO & FM CH R & R
PAR,24,100.,10.,1000.*              EST MATL REORDER
PAR,25,0.02,0.0,,0.003*             M.C. PROC TIME
FIN*
```

APPENDIX C

SPSS ANOVA PROGRAM

COL 1	COL 16
RUN NAME	THREE FACTOR ANOVA
DATA LIST	FIXED MEAN 1-8(3),PLAN 10, LEADT 12, RANDR 14
VAR LABELS	PLAN,NUMBER OF PLANNERS/
	LEADT,MATERIAL LEADTIME/
	RANDR,CHIEF OF R&R AVAILABILITY/
VALUE LABELS	PLAN (1) PESSIMISTIC (2) MOST LIKELY (3) OPTIMISTIC/
	LEADT (1) SLOW (2) AVERAGE (3) FAST/
	RANDR (1) PESSIMISTIC (2) MOST LIKELY (3) OPTIMISTIC/
INPUT MEDIUM	CARD
N OF CASES	54
ANOVA	MEAN BY PLAN,LEADT,RANDR(1,3)/
STATISTICS	2

```
READ INPUT DATA
123.4751 3 2 2
127.2808 3 2 2
128.4799 2 2 2
128.4757 2 2 2
128.7932 1 2 2
127.1355 1 2 2
127.2390 1 2 1
125.7464 1 2 1
127.5222 2 2 1
127.2427 2 2 1
127.3508 3 2 1
127.4976 3 2 1
129.1068 3 2 3
129.0910 3 2 3
127.9120 2 2 3
127.2911 2 2 3
129.5165 1 2 3
128.2581 1 2 3
110.0692 1 3 3
112.5814 1 3 3
110.1079 2 3 3
110.8959 2 3 3
109.5046 3 3 3
108.9980 3 3 3
110.2278 3 3 2
113.1148 3 3 2
112.6559 2 3 2
109.5143 2 3 2
111.3961 1 3 2
112.3692 1 3 2
111.5630 1 3 1
108.5777 1 3 1
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111.1514 2 3 1
110.8745 2 3 1
112.4729 3 3 1
110.9094 3 3 1
145.3149 3 1 1
141.2065 3 1 1
141.6458 2 1 1
141.2939 2 1 1
141.1500 1 1 1
143.9146 1 1 1
142.8412 1 1 2
140.9566 1 1 2
142.2494 2 1 2
142.3027 2 1 2
146.0686 3 1 2
144.2331 3 1 2
140.5437 3 1 3
141.7145 3 1 3
142.1081 2 1 3
140.8070 2 1 3
141.7037 1 1 3
142.9041 1 1 3
FINISH
```

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BIOGRAPHICAL SKETCH OF THE AUTHOR

Lt. St. Gelais was awarded a Bachelor of Science Degree in Civil Engineering from the United States Air Force Academy in May 1978. His only civil engineering assignment since that time was at Davis-Monthan AFB, Arizona where he served as a contract inspector in Construction Management, a missile engineer working with the Titan II missile, and the Chief of Readiness and Logistics. In January 1980, he was selected to attend AFIT in the Graduate Engineering Management program. Upon graduation, he was assigned to Headquarters Strategic Air Command, Engineering and Construction Directorate, Military Related Programs, Offutt AFB, Nebraska. AUTOVON: 271-2467.

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